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TRIZ*fest* - 2017

September 14-16, 2017, Kraków, Poland

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Editor: Valeri Souchkov

Local Organizer:

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The present book of Proceedings includes papers related to the research and development of TRIZ, best practices with TRIZ, cases of practical application of TRIZ, and issues of TRIZ training and education.

All presented papers are double blind peer-reviewed.

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Dear colleagues and friends!

It is an honor and a privilege to greet you at TRIZfest - 2017. Every TRIZ conference is unique and TRIZfest in Kraków is also one of its kind.

Only a year has passed since our last event in Beijing, but strengthening of the TRIZ movement and its deploying all over the globe would impress many.

TRIZ growth in China and India, Singapore and South America, continuation of TRIZ proliferation in South Korea, Europe and other places is a convincing proof that the methodology is taking over its place in the world engineering culture.

Never has a MATRIZ conference had such a multinational participation - we never had representatives from so many countries before.

It is quite indicative that TRIZfest is hosted by Poland this year. TRIZ movement here is gaining strength, more people and companies successfully learn and use TRIZ and in general, innovation is a focal point for Polish industry.

I also would like to notice how many TRIZ conferences have sprung in different parts of the world - several conferences in Europe - Germany, Austria, Slovenia, Asia - China, India, South Korea, Japan and a number of others. It is definitely a very good sign. MATRIZ was, is and will be supporting those as a sponsor or sharing resources and experience.

TRIZfest has a very rich and diverse program this year - TRIZ practitioners from many countries will share their findings in the development of TRIZ methodology, successes of industrial TRIZ applications, using TRIZ in education, in schools, etc.

I would like to wish everyone interesting, constructive and fruitful discussions, efficient networking and to enjoy the wonderful city of Kraków.

Sergei Ikovenko, Dr-Eng, PhD, TRIZ Master
President of the International TRIZ Association (MATRIZ)

Dear TRIZ*fest* 2017 Participants,

For the first time such a huge-scale event as an international TRIZ conference is held in Poland. It is a great honor.

If one considers the variety of modern TRIZ applications, where the methodology is successfully used or the growing number of certified MA TRIZ specialist, it is clearly visible how greatly TRIZ developed during last 15 years.

The TRIZ methodology is widely implemented in large, medium and small enterprises as a pragmatic innovation tool that allows creating systematic competitive advantage.

It is worth to mention that the Republic of Poland was among the very first countries that translated Gienrich Altschuller's books. Although it happened in the 70s, it did not bring rapid development and common usage of TRIZ in the country. However, 5 years ago, group of TRIZ enthusiasts decided to change the situation. The main idea was to popularize, develop and implement the TRIZ methodology in Poland. Due to intensive work, cooperation with a number of ministries, government agendas, entrepreneurship programs and universities the interest to TRIZ methodology in Poland started to grow. Some companies basing on South Korean experiences decided to include the methodology into their corporate culture. It is especially worth to highlight the commitment and support of the Polish Patent Office and its President Mrs. Alicja Adamczak. Her commitment and devotion had enormous influence on TRIZ development in Poland. Due to public seminars, the number of certified MA TRIZ specialists is rapidly growing. Only 5 years ago, there were no more than 10 officially certified people. Nowadays there are 150. Those facts allow us to forecast a bright future for TRIZ development in Poland.

This year the TRIZfest is held in Krakow. We hope that the Conference will be an enjoyable event with interesting lectures and astonishing discussions with a great opportunity to expand contacts, make new friendships and have a great time.

Yours faithfully,

Sergey Yatsunenko
Chief Scientific Officer
NOVISMO Company

Dear TRIZ*fest* 2017 Participants and Readers of the Proceedings,

Welcome to Kraków! It is a pleasure to announce the 13th International Conference "TRIZf*est* 2017" which will be held on September 14-16, 2017, Kraków, Poland.

Just like in the past years, it took some efforts to prepare this conference since this year The Organizing Committee received over 100 paper abstracts from all over the world. The Paper Review Committee and Board worked hard to select best papers to be presented at the event in Kraków.

This year the conference includes papers and presentations focused on the following topics:

- TRIZ research, methodology, development.
- Development of competence with TRIZ.
- Integration of TRIZ with other methods and tools to enhance systematic innovation.
- Sharing experiences with best practices of using and implementing TRIZ.
- Case studies with the use of TRIZ

For the first time, the TRIZ*fest* conference will feature a special session "TRIZ-Pedagogy" dedicated to discussing various issues how TRIZ can help to improve modern education.

We would like to thank all the authors and co-authors who contributed their works to include to these Proceedings and therefore provided considerable impact on further development of TRIZ and its dissemination around the world.

We would like to express our sincere gratitude to all the members of the TRIZ*fest* 2017 Organizing Committee who provided their help and support as well as to the members of the Papers Review Committee who invested their precious time to select the best papers and provide authors with comments how to improve their papers.

And at last but not least, we would like to express thanks to Novismo Sp. z o.o. and all enthustastic partners of MATRIZ in Poland who invested considerable efforts to make the conference possible.

Valeri Souchkov, TRIZ Master
Chair of the TRIZ*fest* 2017 Papers Committee
Vice President, The International TRIZ Association
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A PRAXIOLOGICAL CHAIN MODEL APPLIED TO THE ALGORITHM OF INVENTIVE PROBLEM SOLVING

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Abstract

The paper presents the application of the praxiological chain model to the selected part of the Algorithm of Inventive Problem Solving (ARIZ) considered as a system of actions being performed in order to achieve the desired result while conducting an organised action realisation process. The main aims of this paper include:

- general presentation of the possibilities of using praxiological chains while modelling actions

- verification of the possibility of applying the praxiological models to the actions organised by the Algorithm of Inventive Problems Solving

- identification of the relations of support in the modelled system which are essential for its proper functioning.

According to the structure and system of the algorithm, selected actions were modelled as praxiological chains and linked with each other in order to represent the existing relations of support. The obtained model is another formal representation of the system of actions included in the algorithm offering the possibilities of its analysis. The developed model and the obtained results may be useful during the introduction of the algorithm in real circumstances in order to solve practical problems and/or during developing similar tools in the future.

Keywords: praxiology, praxiological chain model, ARIZ.

1. Actions modelling

Any action may be described as a process of conscious and intentional functioning (of a human being) with incorporated ability to make decisions [1]. Therefore, it could be assumed that a set of three elements is evitable to perform the action. These elements are: a subject (of the action), a tool (which is used) and an object (of the action). What is more, the action is performed in order to achieve a desired goal (that is, in fact, a desired state of the object of the action) and it occurs in some circumstances [2].

Taking into consideration the above-mentioned assumptions, an action may be formally described using a model called the praxiological chain. Such a chain consists of all of the three mentioned elements and may be presented with the use of formula (1) as well as in a graphical form shown in Fig. 1 [2].

$C_i = \langle x_i, y_i, z_i \rangle$, (1)

where:

C_i is the symbol used in order to refer to the praxiological chain i

x_i is the representation of the subject of the action i

y_i is the representation of the tool (the intermediary) within the action i

z_i is the representation of the object of the action i.

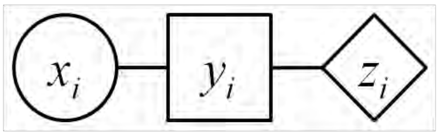

Fig. 1. A graphical representation of the praxiological chain C_i [2]

Combining a number of praxiological chains (or at least two of them) allows one to present the relations of support which occur in the analysed circumstances. The system of chains obtained as a result of the performed analysis of an existing process or during a synthesis of a new one becomes a model which should be used in order to identify the elements inevitable to conduct the process and/or to evaluate the effectiveness of the process. What is more, such a model allows one to focus on the elements which should be better supported or even are still missing in the whole analysed/synthesised system [3].

The relation of support between two chains C_1 and C_2 may be presented with the use of a proper formula (cf. formula (2)) or in a graphical form shown in Fig. 2 [2].

$C_2 \vdash C_1$ (2)

Formula 2 is appropriate to describe any situation when the C_2 chain supports the C_1 chain (in any way). A possible, exemplary relation of support which may occur in such a situation is described more precisely using the scheme presented in the Fig. 2 where the element x_2 of the chain C_2 supports the element y_1 of the chain C_1 relative to its object z_1 [2].

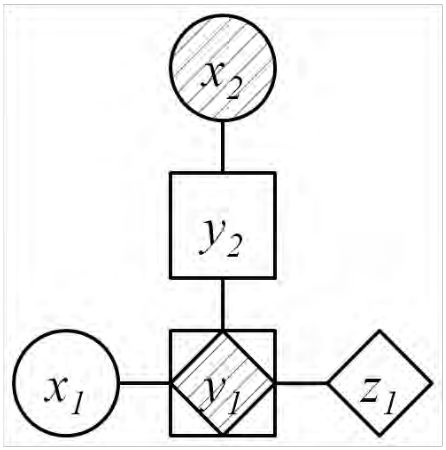

Fig. 2. An exemplary relation of support between chains C_1 and C_2 [2]

A more sophisticated, formal way of denoting precisely the relations of support between two praxiological chains without using the graphical representation (like in the Fig. 2) is presented in [2].

2. Praxiological chain models applied to ARIZ

The whole process of modelling was performed considering the most important assumption presented below.

It was assumed that the problem which is to be solved (or the task which is to be done) occupies the position of a tool in the analysed chain, and the solution which is to be obtained is presented as an object. Generally, this way of modelling may be used at any stage of problem solving if only the previous state of the problem is considered as the tool (in the sense of the chain element), and the succeeding state of the problem (the result) is considered as the object (cf. [4]). Obviously, the tools used for solving the problem (e. g. inventive principles, inventive standards or ARIZ [5, 6, 7]) take the positions of other tools in the praxiological sense, so the obtained praxiological chain was presented in a more complex graphical form (Fig. 3). The above-mentioned relations are shown in the Fig. 3.

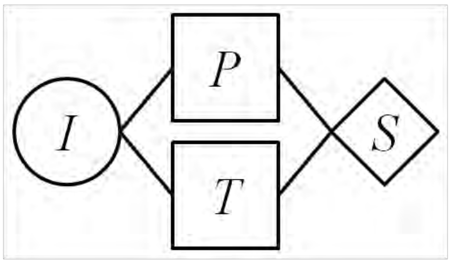

Fig. 3. A praxiological chain representing the action related to problem solving; *I* – inventor, *P* - problem (previous state of the problem), *T* – tools used for problem solving, *S* – solution (succeeding state of the problem)

The model presented in the Fig. 3 is described using the set of formulas (3 – 7):

$C_1 = \langle x_1, \{y^1{}_1, y^2{}_1\}, z_1 \rangle$, (3)

$x_1 = I$, (4)

$z_1 = S$, (5)

$y^1{}_1 = P$, (6)

$y^2{}_1 = T$. (7)

The described model may be used as a simple, single part of an algorithm in order to present an action when an item is inputted, processed and finally outputted.

The Algorithm of Inventive Problem Solving (ARIZ) is organised as a set of actions. Therefore, the whole set could be modelled with the use of praxiological chains, in the way presented above. The algorithm chosen for the conducted analysis is ARIZ-77, and exactly the steps from 1.1 to 1.3 covered by its part 1 [8].

Part 1 of ARIZ-77 refers to the selection of the task to be solved [8], and includes nine steps. The first three of them are listed below:

1.1 – formulate the final aim of the solution of the task

1.2 – verify if the goal could be achieved in another way

1.3 – choose the more purposeful task to be solved (using additional criteria of choice referring to the system development limitations and the type of task to be solved).

Praxiological models constructed respectively for the actions included in these steps are presented in the Fig. 4, 5 and 6.

The step 1.1 consists of five parts (a – e). Each part was considered as a separate action and modelled as a praxiological chain. The indexes a – e of the elements of the chains shown in the Fig. 4 refer to the mentioned parts of the step.

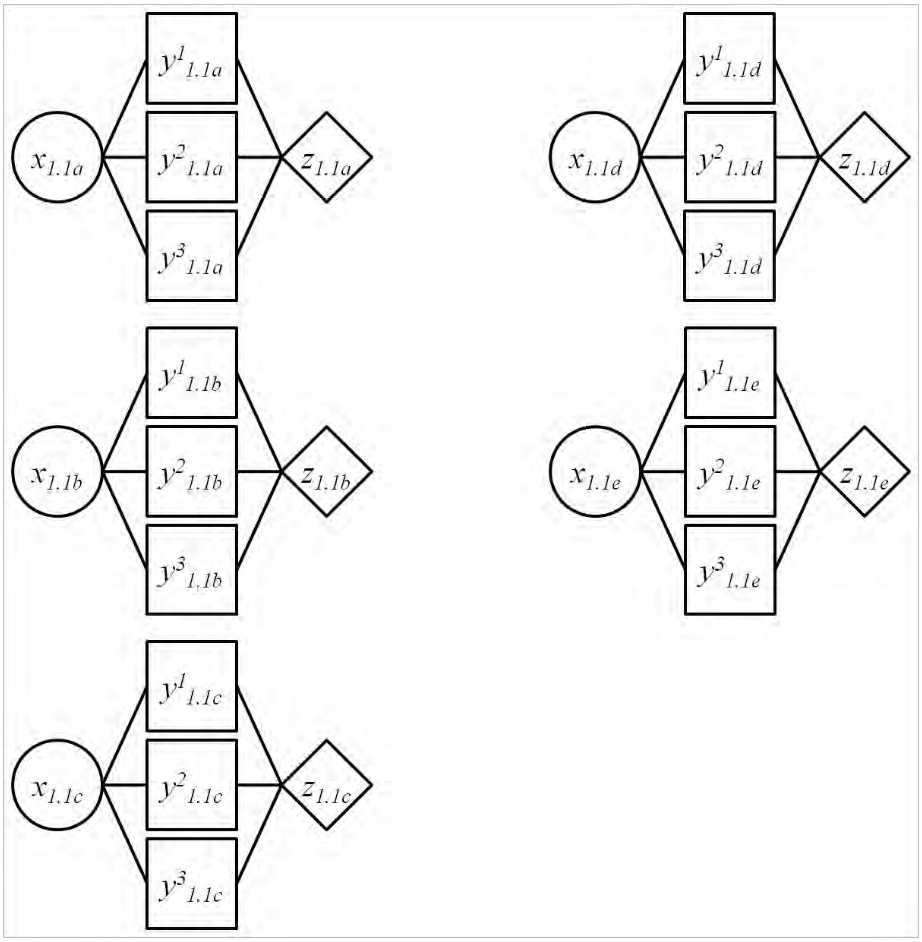

Fig. 4. Praxiological models of the actions included in the step 1.1 of ARIZ-77
(chains $C_{1.1a}$, $C_{1.1b}$, $C_{1.1c}$, $C_{1.1d}$ and $C_{1.1e}$)

The elements labelled using the symbols presented in the Fig. 4 are as follows:

- $x_{1.1a}$, $x_{1.1b}$, ..., $x_{1.1e}$ – the person solving the task (e. g. an inventor or a designer)
- $y^1_{1.1a}$, $y^1_{1.1b}$, ..., $y^1_{1.1e}$ – the task to be solved
- $y^2_{1.1a}$, $y^2_{1.1b}$, ..., $y^2_{1.1e}$ – the guidelines present in the corresponding part (a – e) of the step 1.1 of ARIZ
- $y^3_{1.1a}$, $y^3_{1.1b}$, ..., $y^3_{1.1e}$ – the knowledge and skills of the person solving the task (cf. [3])
- $z_{1.1a}$ – the characteristics of the object to be changed
- $z_{1.1b}$ – the characteristics of the object which mustn't be changed
- $z_{1.1c}$ – the costs which decrease once the task is solved
- $z_{1.1d}$ – the accepted outlays
- $z_{1.1e}$ – the basis technical and economic index to be improved.

Though some of the elements of the separate chains shown in the Fig. 4 occur in different actions, they are in fact the same elements. Therefore, the equations 8 – 11 may be written:

$y^1_{1.1a} = y^1_{1.1b} = y^1_{1.1c} = y^1_{1.1d} = y^1_{1.1e} = y^1_{1.1}$, (8)

when the task is being solved individually:

$x_{1.1a} = x_{1.1b} = x_{1.1c} = x_{1.1d} = x_{1.1e} = x_{1.1}$, (9)

$y^3_{1.1a} = y^3_{1.1b} = y^3_{1.1c} = y^3_{1.1d} = y^3_{1.1e} = y^3_{1.1}$, (10)

and obviously always

$y^2_{1.1a} \neq y^2_{1.1b} \neq y^2_{1.1c} \neq y^2_{1.1d} \neq y^2_{1.1e}$. (11)

A similar analysis may be conducted for the steps 1.2 and 1.3. The constructed models are presented in the Fig. 5 and 6 and described below.

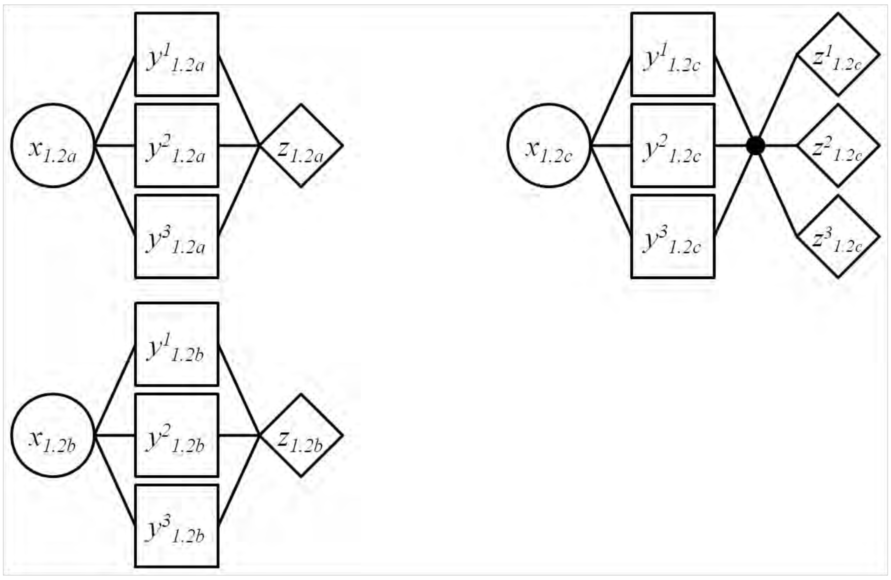

Fig. 5. Praxiological models of the actions included in the step 1.2 of ARIZ-77
(chains $C_{1.2a}$, $C_{1.2b}$ and $C_{1.2c}$)

The meanings of the symbols in the Fig. 5 are as follows:

- $x_{1.2a}$, $x_{1.2b}$, $x_{1.2c}$ – the person solving the task (e. g. an inventor or a designer)
- $y^1_{1.2a}$, $y^1_{1.2b}$, $y^1_{1.2c}$ – the task to be solved
- $y^2_{1.2a}$, $y^2_{1.2b}$, $y^2_{1.2c}$ – the guidelines present in the corresponding part (a – c) of the step 1.2 of ARIZ
- $y^3_{1.2a}$, $y^3_{1.2b}$, $y^3_{1.2c}$ – the knowledge and skills of the person solving the task
- $z_{1.2a}$ – the task reformulated for the circumstances of the supersystem
- $z_{1.2b}$ – the task reformulated for the circumstances of the subsystems
- $z^1_{1.2c}$ – the task reformulated for the opposite action and the circumstances of the supersystem
- $z^2_{1.2c}$ – the task reformulated for the opposite action and the circumstances of the system
- $z^3_{1.2c}$ – the task reformulated for the opposite action and the circumstances of the subsystem.

Consequently, the equations 12 – 15 may be written:

$y^1_{1.2a} = y^1_{1.2b} = y^1_{1.2c} = y^1_{1.2} = y^1_{1.1}$, (12) when the task is being solved individually:

$x_{1.2a} = x_{1.2b} = x_{1.2c} = x_{1.2} = x_{1.1}$, (13)

$y^3_{1.2a} = y^3_{1.2b} = y^3_{1.2c} = y^3_{1.2} = y^3_{1.1}$, (14)

and always

$y^2_{1.2a} \neq y^2_{1.2b} \neq y^2_{1.2c}$. (15)

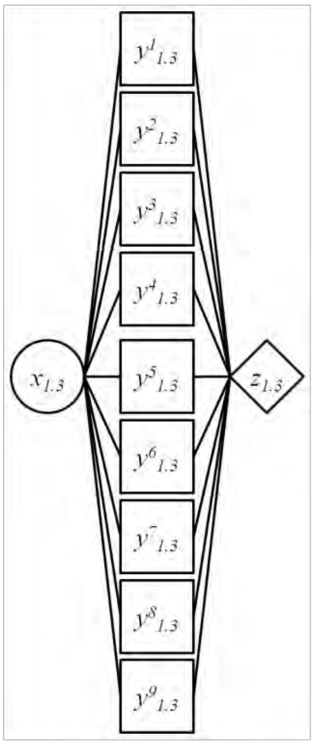

Fig. 6. Praxiological models of the action included in the step 1.3 of ARIZ-77 (chain $C_{1.3}$)

The meanings of the symbols used in the Fig. 6 are as follows:

- $x_{1.3}$ – the person solving the task (e. g. an inventor or a designer)
- $y^1_{1.3}$ – the task to be solved
- $y^2_{1.3}$ – the guidelines present in the step 1.3 of ARIZ
- $y^3_{1.3}$ – the knowledge and skills of the person solving the task
- $y^4_{1.3}$, $y^5_{1.3}$, $y^6_{1.3}$, $y^7_{1.3}$, $y^8_{1.3}$ – the reformulated task (cf. step 1.2 and equations 19 – 23)
- $y^9_{1.3}$ – the additional criteria of choice
- $z_{1.3}$ – the task finally selected to be solved.

Considering the structures of ARIZ-77 and models built the equations 16 – 23 should be presented. Some of them (19 – 23) give grounds for writing the relations of support (33 – 35).

$y^1_{1.1} = y^1_{1.2} = y^1_{1.3}$, (16)

for the task being solved individually:

$x_{1.1} = x_{1.2} = x_{1.3}$, (17)

$y^3_{1.1} = y^3_{1.2} = y^3_{1.3}$, (18)

and generally:

$z_{1.2a} = y^4_{1.3}$, (19)

$z_{1.2b} = y^5_{1.3}$, (20)

$z^1_{1.2c} = y^6_{1.3}$, (21)

$z^2_{1.2c} = y^7_{1.3}$, (22)

$z^3_{1.2c} = y^8_{1.3}$. (23)

But there are some other interactions between the chains which were not described yet. All of the objects *z* included in the chains built for the step 1.1 are later used by the person solving the task. The results of the actions performed for the step 1.1 support the inventor or the designer while organising his or her work for the steps 1.2 and 1.3. This fact may be presented using the chains $C_{1.2'}$ and $C_{1.3'}$. The chain $C_{1.2'}$ is shown in the Fig. 7.

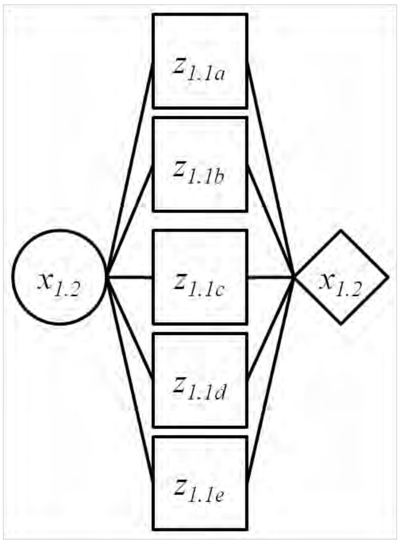

Fig. 7. The chain $C_{1.2'}$

Both of the chains were described using the formulas 24 and 25:

$C_{1.2'} = \langle x_{1.2}, \{z_{1.1a}, z_{1.1b}, z_{1.1c}, z_{1.1d}, z_{1.1e}\}, x_{1.2}\rangle$, (24)

$C_{1.3'} = \langle x_{1.3}, \{z_{1.1a}, z_{1.1b}, z_{1.1c}, z_{1.1d}, z_{1.1e}\}, x_{1.3}\rangle$. (25)

Finally, the relations of support which occur between the praxiological chains modelling the steps 1.1, 1.2 and 1.3 of ARIZ-77 are as follows (26 – 35):

$C_{1.1a} \vdash C_{1.2'} \wedge C_{1.1a} \vdash C_{1.3'}$, (26)

$C_{1.1b} \vdash C_{1.2'} \wedge C_{1.1b} \vdash C_{1.3'}$, (27)

$C_{1.1c} \vdash C_{1.2'} \wedge C_{1.1c} \vdash C_{1.3'}$, (28)

$C_{1.1d} \vdash C_{1.2'} \wedge C_{1.1d} \vdash C_{1.3'}$, (29)

$C_{1.1e} \vdash C_{1.2'} \wedge C_{1.1e} \vdash C_{1.3'}$, (30)

$C_{1.2'} \vdash C_{1.2a} \wedge C_{1.2'} \vdash C_{1.2b} \wedge C_{1.2'} \vdash C_{1.2c}$, (31)

$C_{1.3'} \vdash C_{1.3}$, (32)

$C_{1.2a} \vdash C_{1.3}$, (33)

$C_{1.2b} \vdash C_{1.3}$, (34)

$C_{1.2c} \vdash C_{1.3}$. (35)

The above-mentioned formulas represent the structure of the analysed algorithm in a formal way considering the indicated relations of support.

3. Conclusions

An exemplary application of praxiological chains to the part of the Algorithm of Inventive Problem Solving was successfully performed and presented in the paper. Such an analysis may be conducted for different methods and/or algorithms, and especially more modern tools used in design methodology and inventive engineering (e. g. ARIZ-85C [5, 7]).

Considering the formal way of modelling actions, the formulas 26 – 35 clearly show that the analysed part of the algorithm is logically constructed. All of the indicated actions support the elements of the last chain $C_{1.3}$ which means that all of them aim at achieving the final result that is, in this case, the formulation of the task eventually selected to be solved. However, some improvements could still be introduced within the analysed part of the algorithm relative to the wording of the step 1.1 in order to strengthen the relation between the steps 1.1 and 1.2 as well as 1.1 and 1.3. The final aim of the solution of the task mentioned in the step 1.1 should be defined more precisely in order to better support the inventor moving from the step 1.1 to the following steps. Such an improvement should allow one to avoid potential misapprehensions.

The conducted analysis was focused on the formal relations which occur between the actions performed due to the guidelines of ARIZ but the psychological impact of the wording of the steps of the algorithm on the person solving the task was not considered. It could become a part of a more complex analysis in the future.

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A SIMPLE WAY TO PERFORM CECA AND GENERATE IDEAS IN PRACTICE

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Abstract

Cause-Effect Chain Analysis (CECA) is an improved method of RCA (Root-Cause Analysis) created by GEN3 partners. In practice, when a team of engineers performs Cause-Effect Chain Analysis to a technical problem, different people usually have very different opinions and they tend to spend a lot of time arguing. It wastes a lot of energy when people argues about CECA, and it is important to help participants discuss in a constructive way so that they could continuously expand their thinking instead of arguing on some unnecessary topics.

This article suggest that there is 'Model Answer' for CECA of each technical problem and suggest three principles when applying CECA: 1. We analyze the cause rather than purpose when answering the question of 'Why'; 2. When analyzing the cause, always find out the scientific phenomenon and describe causes according to scientific laws; 3. MECE (Mutually Exclusive Collectively Exhaustive) principle. If we apply these principles, we could easily achieve consensus when we discuss about CECA. Also, the author suggests that we could combine CECA and 'Why-What If-How' question to generate ideas and contradictions after CECA analysis.

Keywords: CECA; MECE; Idea Generation.

1. Introduction

Root Cause Analysis (RCA) [1] is a frequently used tool in quality management and problem solving. It is a structured methodology that identifies root cause(s) so that we could solve the problem sustainably. Based on RCA, GEN3 partners created a tool Cause-Effect Chain Analysis[2]. Now it has become a very frequently used and quite effective tool in TRIZ practice.

The steps of CECA that GEN3 partners suggested include: 1. List the starting disadvantage; 2. Analyze the conditions that causes the starting disadvantage and generate the intermediate disadvantages; 3. Link the intermediate disadvantages with 'And', 'Or'; 4. Pick the key disadvantages.

Abramov[3] compared CECA with traditional RCA tools and suggested that CECA is superior because it identifies an exhaustive set(s) of key disadvantages to be solved, while RCA does not guarantee that all root causes will be identified.

However, it is not easy for practitioners to perform a CECA process. The problem is that there is lack of standards for judging whether an CECA is 'correct' or 'wrong'. Different people have different understanding.

2. Common challenges for CECA in practice

When using CECA, engineers usually have different understanding and different opinions, so when they perform an analysis to a technical problem, different people have very different layout of the cause-effect chain. For example, in rainy days, when we drive a car, there is mist on the windshield, and it's inconvenient for driver to see through the windshield. When people analyze this problem, they could have totally different versions. See below different versions.

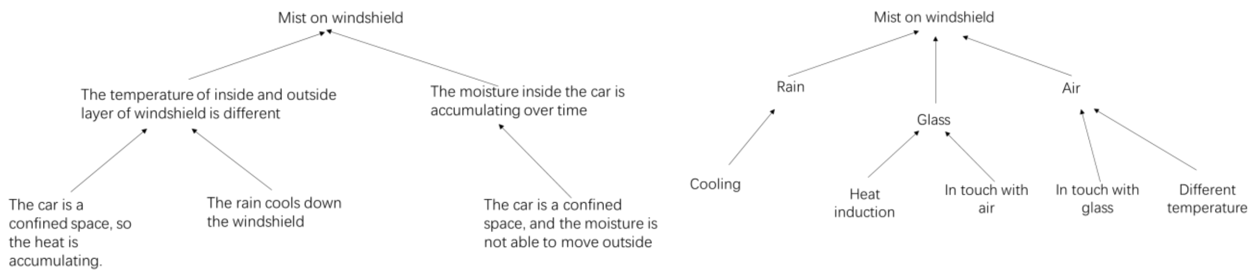

Fig. 1. Two different cause-effect chain analysis performed by two different people

The reason why different people have different CECA analysis include: 1. Different thinking patterns of the practitioners; 2. Different opinions about how to lay out differnt factors on a CECA tree format; 3. There is no standard criteria about how we should lay out the logic behind a problem.

It is easy to attribute this problem to the practitioner themselves, but we could also ask a further question: Is it possible that whoever goes through the CECA process will get the same results?

To put it in another way, when we analyze a problem, is there a model answer for cause-effect chain analysis? If there is a model answer, then it means that different people should have the same version of analysis. After all, the engineering system does not change in respect to the observer, there must be a standard version of CECA for any technical problem. However, this is seldom seen in practice. So the question is: how do we manage the process so that every one will reach the same answer if they follow the process?

3. Cause-Effect Logic.

When we perform CECA, is there a model answer? The answer is yes.

When we analyze a problem with CECA, how do we make sure we are doing it correctly? The argument here is that if there is an exclusive and correct answer for each step of the analysis, then there is an exclusive and correct answer for the whole analysis. In practice, we found that people have different versions of CECA only because there is no standard for cause-effect logic in every small step. So how to make sure every one follow the right logic in every step? The author suggests three key princples.

3.1 Principle 1: "Cause" rather than "Purpose"

When we analyze the cause-effect, we simply ask "why". However, there are two possible scenarios when you answer the question of "why". The first one is clarifying purpose or intention. For example, when we ask a person 'Why do you ride a bicycle to go to work?', the answer might be 'To keep fit'. In this case, the person is clarifying the purpose. And the second scenario is clarifying causes. For example, when we ask a person 'Why do you ride a bicycle to go to work?' The answer might be 'Because my car had a flat tire.' In this case, the person is clarifying the cause. Souchkov [4] suggests that when we analyze a problem, we should clarify cause instead of purpose. In practice, the author found that if we analyze from the cause rather than purpose perspective, then we could better describe the essential logic behind a problem.

3.2 Principle 2: Refer to physical, chemical or other scientific law

Traditionally, the analysis part of a problem is a subjective process that rely much on the practitioner's knowledge and skills. How could we make it a more objective rather than subjective process? The author suggests if we describe the problem from scientific perspective, then everyone could have the same understanding.

For example, if we analyse the problem of water leakage in a pipe. If we list the key disadvantages in a subjective way, then some people will claim corrosion is the key problem, while others argue the quality of the pipe is not good enough. However, if we define the problem from the physical phenomenon perspective, water leakage is flow of water in essence. And the scientific law for water flow is movement of water driven by gravity. So the factors related with this phenomenon include: 1) passage for water; 2) gravity is greater than drag force. Then we could further describe the physical phenomenon of the causes and analyse in a deeper way. Here are the steps for following scientific law:

Step 1 Describe the physical, chemical or other scientific phenomenon.

Step 2 Describe the scientific law of this phenomenon.

Step 3 Refer to the formula or equation and check all the factors related with the scientific law.

3.3 Principle 3:MECE(mutually exclusive and collectively exhaustive).

MECE stands for "mutually exclusive and collectively exhaustive" and is one of the hallmarks of problem solving at McKinsey. **Mutually exclusive** suggests that information should be grouped into categories so that each category is separate and distinct without any overlap; and **Collectively exhaustive** suggests that all categories taken together should deal with all possible options without leaving any gaps [5]. Following the scientific laws makes it easier to achieve MECE requirement.

4. An Example.

If we are able to make sure every step for CECA is correct, then we could start to make sure the whole analysis is correct. Because for each step it is mutually exclusive and collectively exhaustive, the whole map will be collectively reflecting the essence of the engineering problem, and people could easily follow the logic. For example, below is the analysis of the aforementioned windshield mist problem.

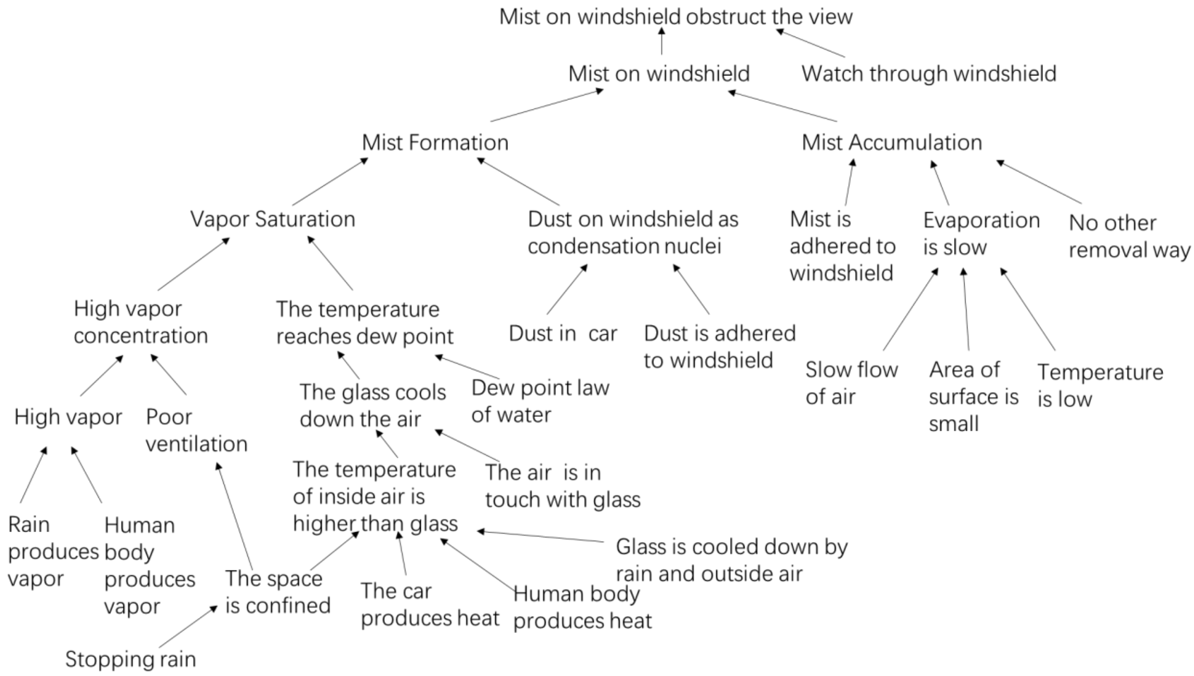

Fig. 2. The “Model Answer” for the windshield mist problem.

Still, this might not be the only correct answer for the analysis, but it almost is. When people look at the analysis, they may find out something the practitioner misses, but normally people stop debating, because the whole analysis is performed in a logic way following the three principles the author suggested.

5. The golden creative questions

5.1 The golden creative questions and when we should use them

Berger [6] suggested that by asking Why, What if, and How, people’s thinking will advance through three critical stages of problem-solving. “Why” questions help us understand why the problem exists, why it hasn’t been solved already, and why it might be worth tackling. “What if” questions can be used to explore fresh ideas for possible improvements or solutions to the problem, from a hypothetical standpoint. And “How” question focuses on practical, action-oriented ideas, e.g. how to give form to ideas, how to test and refine them with the goal of transforming possibility into reality.

5.2 An example

In the example of “Mist on windshield”, one of the causes is “watch through the windshield”, and we could ask the three questions to the fact that the driver sees through the windshield. See below table.

Table 1

Example: The Golden Creative Questions

Question	Why should we watch through windshield?
Answer	Because the windshield is in the direct line between the objects and eyes
Question	What If we donot need to watch through windshield?
Answer	We should find out other ways to see all the objects in front.
Question	How could we see all the things in front but not through windshield?
Answer	Streaming video; infrared dedection technology;

5.3 Challenge with application of the golden creative questions

When we use the golden questions, one of the top challenges is about where should we start from. For example, when we ask these questions for a coffee mug, we could start from different aspects, such as:

- Why is the coffee mug round? What if it is square? How could we make an excellent square mug?
- Why is the coffee mug made of ceramic? What if it is made of edible stuff? How could we make an edible mug?
- Why is the surface of coffe mug smooth? What if the surface is rough? How could we make an interesting mug with rough surface.

In different directions, there will be many different ideas. So which direction should we pursue? How do we make sure that we are targeting the right direction? The "Why-What If-How" question does not touch these questions. Because CECA is a tool that provide clear direction for problem solving, so we believe it will help tackle this challenge.

6. A promising possibility: generating all the possibilities related to a technical problem.

If we could predict all the possibilities related to a technical problem, or to an engineering system, and then the advantage is that we will have very good chance to solve the problem from the root-cause level, at least we will out-compete other players from thinking level.

Is it possible to generate all the possibilities? From the engineering system perspective, it is very difficult; However, from the technical problem perspective, it is plausible.

Because CECA lays out the underlying logic of a specific problem, and the "Why-What If-How" question provide divergent thinking, so if we combine these two tools together, theoretically we could generate all the possible ideas.

In the Cause-Effect Chain Analysis, we have articulated all the current situation, and we already asked "Why", then it's easy for us to ask "What If" and "How" to generate new ideas based on CECA. Here are the key steps the author suggests:

Step 1. Screen all the lines in CECA and identify key starting points. We work through all the sub-branches of the CECA, and define every possible point where we could start to ask the "Why-What If-How" question.

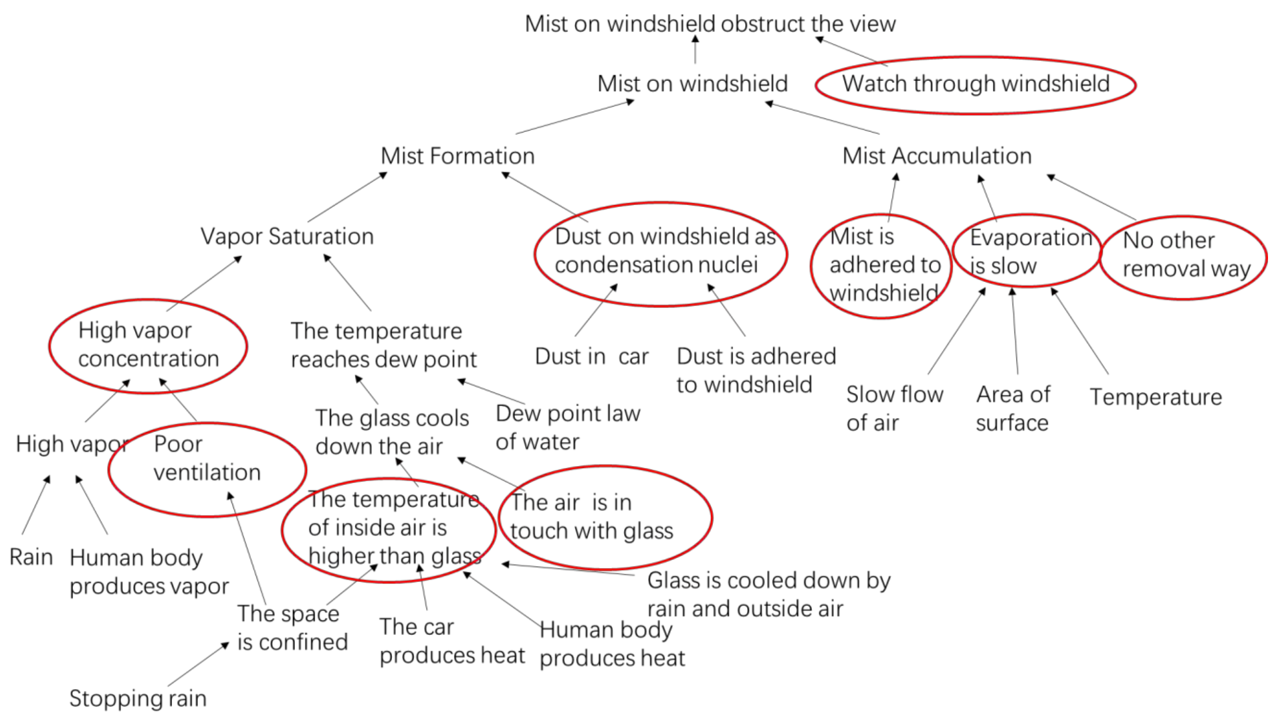

Fig. 2. CECA of "Mist on Windshield" problem with key starting points highlighted.

Step 2. Ask "What If" and "How" for each point. With the key points defined from CECA, we started to ask the three questions for each point. Actually we have already answered the question of "Why" in CECA, but to keep the logic, we still put the "Why" answer in the below table:

Table 2

The Creative Questions based on CECA

	Why	What If	How
Question	Why should we watch through windshield?	What If we donot need to watch through windshield?	How could we see all the things in front but not through windshield?
Answer	Because the windshield is in the direct line between the objects and eyes	We should find out other ways to see all the objects in front.	Streaming video; infrared dedection technology;
Question	Why is there high vapor in the car?	What if the air is always very dry?	How could we dry the air in the car?
Answer	Because the air is humid and the ventilation is poor	We should find out how to dry the air.	Dehumidifier;
Question	Why is the ventilation poor in the car?	What if the ventilation is very good?	How could we stop rain but keep very good ventilation?
Answer	Because it's a confined space to stop rain and heat loss	We should find out how to stop rain and heat loss	Waterproof and breathable structure or material.
Question	Why is the temperature of inside air higher than the glass?	What if the temperature of inside air is equal or lower than the glass?	How could we make the temperature of inside air equal or lower than glass?
Answer	Because the car and human body are releasing heat. And the glass is cooled down by outside air and rain	We should cool down the inside air or heat the glass	Cooling down the air; heating the glass
Question	Why is air directly in touch with glass?	What if the air is not directly in touch with glass?	How could we make the air not directly in touch with glass?
Answer	Because the air is everywhere	We should keep the air away from glass	No idea.
Question	Why is there dust on windshield?	What if there is no dust on windshield?	How could we make sure there is no dust on windshield?
Answer	Because there is dust in the air and the dust is adhered to the glass	We should either clean the dust or make sure dust is not adhered to the glass	Blowing air; anti-adhesion coating;
Question	Why is mist adhered to windshield?	What if the mist is not adhered to windshiled?	How could we make sure the mist is not adhered to windshield?
Answer	Natural property of glass	We should find out how.	Ultra-hydrophobic coating.
Question	Why is evaporation very slow on windshield?	What if the evaporation is very fast on windshield?	How could we make the air flowing fast?
Answer	Because the air is not flowing	We should make sure air is flowing fast	Blowing air;
Question	Why isn't mist removed?	What if the mist is always removed?	How could we remove mist all the time?
Answer	No convenient solution available	We should have the removal solution	Inside wiper; Cleaning rag;

Step 3. Generate ideas and contradictions. Based on the three questions, we generated the below ideas and contradictions:

Table 3

Ideas and Contradictions generated

Idea	
1	Streaming video;
2	Infrared dedection technology;
3	Dehumidifier;
4	Blowing air;
5	Anti-adhesion coating;
6	Ultra-hydrophobic coating;
7	Inside wiper;
8	Cleaning rag;

7. Conclusion.

In this article, the author tried to solve the common challenge of having very different versions of CECA when different people work on the same technical problem. There should be a "Model Answer" for CECA, as the technical problem does not change when different people analyse the problem. To solve this problem, we need to guarantee that when different people work on a small step, they get the same answer. So the author suggested three principles that help people to discover all the causes and describe it in a logical way.

According to the author's experience, when engineers follow the three principles, they usually get much better versions of CECA, and different people tend to achieve the same version.

Also, the author suggested that CECA should be followed by the application of "Why-What If-How" question, because this will help generate all the possibilities related with the technical problem. The steps have been explained in the example of "mist on windshield" problem.

So the author suggested a simple way to perform CECA more effectively and to generate all the possible ideas related to a technical problem. The future research might focus on whether the three principles for CECA are the best principles, and whether combining CECA and "Why-What If-How" question improves the effectiveness and efficiency of solving technical problems.

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AHP BASED MULTI-CRITERIA FUNCTION ANALYSIS AS A TRIZ TOOL FOR COMPLEX TECHNICAL SYSTEMS

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Abstract

This paper presents a modified component importance analysis as a TRIZ tool for complex technical systems modelling and evaluation. A marine diesel fuel injector is used as an example of a complex technical system. The necessity for further development of the function analysis as an effective TRIZ tool is highlighted. Some of the problems encountered in modelling complex technical systems is pointed out. A multi-criteria function analysis with weighted criteria of component importance based on the Analytical Hierarchy Process (AHP) is introduced and the basic criteria for a system component performance and quality evaluation are presented. Results of analyses are presented using weighted criteria and classic function analysis is presented with equal weights.

Keywords: function analysis, importance analysis, complex system, system modelling, weighted criteria, Analytical Hierarchy Process, AHP, multi-criteria analysis.

1. Introduction

Function analysis is a TRIZ tool derived from the theory of systems used at the stage of mapping and assessing a problem [1]. This analysis is also utilized for identifying a key problem in the process of solving inventive problems [2, 3, 4]. Function analysis primarily aims at:

- understanding problems by identifying the relationships between components of the system and of the supersystem and modelling these;
- Finding the existing and potential problems related to system functionality;
- Identifying problems that can be resolved with other TRIZ tools;
- Optimization of the system operation by reducing the number of components while preserving system functionality;
- Modification of existing patents to find patentable solutions having the same functionality

The steps of the function analysis process are as follows [2]:

1. Deconstructing a system and supersystem, namely the isolation of components of the system and components of the supersystem, with which the analysed system interacts.
2. Identifying interactions and indicating them in a relationship matrix.
3. Defining the individual functions for each component, subject to interactions.
4. Determining the direction of each identified function of the components of a system or supersystem.
5. Determining of the type of interaction for each identified function of a system's or supersystem's components.

6. Create a ranking of identified problems based on each component's negative impact on the obtained total value of the system (functionality, efficiency, quality).

This paper is focused on the last step of the function analysis process. The ranking of identified problems is normally created by mutual comparison of individual problems associated the operation of each component of the system [5, 6]. An example of such a variant-based assessment has been presented in section 3.1 of this paper. It is possible for several criteria to be considered, which can then be aggregated; however, this approach does not take into account the ranks of individual criteria and hence the importance of the use of individual rankings for the established criteria. To illustrate the solution to this problem we may determine the final ranking as a weighted average of assessments from individual rankings [7]. However, there remains a matter of indicating weights for particular criteria.

According to the authors, the application of AHP method is a valuable tool for determining the weights of individual criteria, individual rankings and, the aggregated ranking. This method is advantageous as it is possible to quickly determine the importance of criteria and of individual problems in the analysed system. In addition, not only the mutual relation such as "more important" and "less important" is assessed, but also the degree of mutual ratio of importance is expressed on the scale of the intensity. With the above in mind, the authors have attempted to adapt the AHP methodology for the implementation of the latter stage of the function analysis, as shown in the example of the fuel injector in this paper.

2. AHP as a tool for multi-criteria decision-making

The AHP method, developed in 1970 by Thomas L. Saaty, is one of the multi-criteria methods of hierarchical decision problem analysis. It allows the deconstruction of a complex decision problem and result in a ranking for the finite set of alternatives, w_i, according to selected importance criteria, k_i [8]. Figure 1 shows an example hierarchical structure of a decision making process (according to the AHP) for a problem of ordering five analysed alternatives in terms of six different criteria.

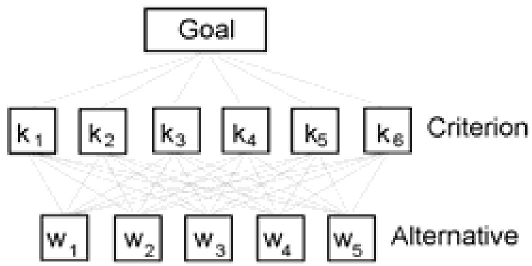

Fig. 1. Example hierarchical structure of a decision making process according to the AHP

After creating a hierarchical problem model by means of the AHP method and pairwise comparison [7], criteria relevance is determined as a level of their dominance relation (Table 1). The range of the allowed dominance levels is between 1 and 9. The relative alternative relevance index - criterion k_i superiority to criterion k_j – is expressed by a_{ij} according to the formula:

$$a_{ij} = \frac{e_i}{e_j}, \quad i, j = 1,2...n \qquad (1)$$

where: e_i – absolute criterion rank k_i,

e_j – absolute criterion rank k_j,

while $a_{ij} \in \{1,2...9\}$.

Table 1

The fundamental scale used in AHP [9]

Importance on an absolute scale	**Definition**	**Explanation**
1	Equal importance	Two activities equally contribute to the objective
3	Moderate importance on one over another	Experience and judgment moderately favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

Coefficients, a_{ij}, of the relation between criteria, e_i, are grouped in square matrix **A**, while $a_{ij} = \frac{1}{a_{ji}}$ for i,j=1,2…n. Table 2 presents an example of comparison matrix **A** with a weight coefficients vector.

Table 2

Example comparison matrix **A** with a weight coefficients vector [8]

Criterion	k_1	k_2	k_3	k_4		w_i
k_1	1	3	1/5	3		w_1
k_2	1/3	1	1/9	1		w_2
k_3	5	9	1	1/7		w_3
k_4	1/3	1	7	1		w_4

With regard to the fact that the i-th verse of the comparison matrix is the i-th column reciprocity (i=1, 2…, n), a relation is established:

$$\mathbf{A}\vec{\mathbf{w}} = n\vec{\mathbf{w}} \qquad (2)$$

where: $\vec{w}$ – is a column vector with elements $w_1, w_2 \dots w_n$.

The elements of the eigenvector $\vec{\mathbf{w}}$ represent weight coefficients and the priorities of particular hierarchical structure components. The elements describe the estimated share in the superior aim achievement; therefore, they express the preferences associated with the elements by the decision-maker. Using comparison matrix **A** and unit matrix **I**, we can calculate an unknown vector ***w*** by means of the system of equations:

$$(\mathbf{A} - n\mathbf{I})\vec{\mathbf{w}} = 0 \qquad (3)$$

To solve the system of equations, we can use Horner's scheme or an iterative method [8]. The system has a non-zero solution only if n is the principal eigenvalue of matrix **A**. With regard to a specific construction of matrix **A** it is the only non-zero principal eigenvalue. The task can be expressed as the following system of equations:

$$\mathbf{A}\vec{\mathbf{w}} = l_{\max}\vec{\mathbf{w}} \quad (4)$$

where: $l_{\max}$ – is the maximum principal eigenvalue for the comparison matrix the order n.

Table 3 shows an example of the vector of the alternatives ranks. The elements of the eigenvector in matrix **A** represent weight coefficients – priorities according to subsequent elements at each level of the hierarchy. Data on global preferences, taken from evaluators, are normalized to estimate weight coefficients for the criteria as their relative share in achieving the main aim which is a synthetic criterion. In Saaty's method, the required evaluation consistency is a prerequisite, expressed by the consistency index C_I of a comparison matrix whose value should not exceed 0,1. The consistency index describes the preservation of the transitive relation of the components dominance and evaluation credibility; obtained from experts or decision-makers.

Table 3

Example vector of alternatives ranks [8]

Alternative	**W**
Choice A	0,123
Choice B	0,323
Choice C	0,143
Choice D	0,232
Choice E	0,279
$\sum$	1,00

Coefficient C_I is given by:

$$C_I = \frac{l_{\max} - n}{n-1} \quad (5)$$

In the case of full evaluation of the consistency of dominance $l_{\max} = n$ and $C_I = 0$. Coefficient C_I is calculated with reference to random index R_I, which is a mean value of C_I for a large number of randomly generated comparison matrices (Table 4).

Table 4

Values of random index R_I [9]

n	2	3	4	5	6	7	8	9	10
R_I	0	0,52	0,89	1,11	1,25	1,35	1,4	1,45	1,49

As a result of dividing index C_I by random index values ratio C_R (consistency ratio) is obtained.

$$C_R = \frac{C_I}{R_I} \quad (6)$$

The value of the consistency ratio not exceeding 0,1 means that the mutual parameter comparisons satisfy the consistency condition [9]. In the case when $C_R > 0,1$ the process of mutual relation evaluation between alternatives and/or criteria must be repeated.

The grades aggregation in the AHP method is executed by means of an additive usability function which synthesizes the criteria shares (weights) and values of the fulfilled objective fractional function by means of each criterion. The pairwise comparison of alternative results in the relative valuation of alternative shares in terms of the main aim achievement.

3. TRIZ-based function analysis

3.1. Analysed system

The subject of analysis is the marine diesel engine fuel injector. It is an object that is designed to feed the fuel at the correct pressure to the combustion chamber and to spray it properly [10, 11]. The cross-section of the analysed object and the critical components are shown in Figure 2. The main components of the system are: 1 – retaining nut, 2 – nozzle body, 3 – needle valve, 4 – nozzle cap nut, 5 – intermediate spindle, 6 – spring, 7 – O-ring, 8 – dowel pin, 9 – adjusting nut and washer, 10 – injector body.

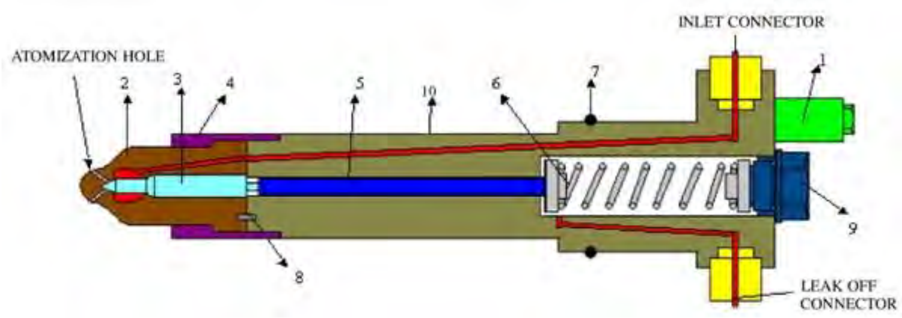

Fig. 2. Object of analysis and their components [13]

For the purposes of this analysis, the most important components of the supersystem were identified: engine block, high-pressure pipe / inlet connector, drain pipe / leak off connector, combustion chamber, fuel oil and the operator / maintenance engineer.

3.2. System modelling

The system has been modelled according to TRIZ rules. A matrix of interactions has been built as shown in table 5, this was used to develop a component-function diagram shown in figure 3. This diagram shows the components of the system and of the supersystem, as well as indicating and describing their inter-relationships (direct contact). For each relationship, the direction of impact and the type were indicated. We have considered following the types of impact: positive, harmful (red arrows) and potentially insufficient (an arrow with a dotted line).

Table 5

Matrix of interactions

Component name	Components of the system										Supersystem					
	Retaining nut	Nozzle body	Needle valve	Nozzle cap nut	Intermediate spindle	Spring	O-ring	Dowel pin	Adjusting nut and washer	Injector body	Engine block	High pressure pipe	Drain pipe / leak off	Combustion chamber	Fuel oil	Operator / maintenance engineer
Retaining nut	x									x	x					x
Nozzle body		x	x	x				x		x					x	
Needle valve		x	x		x										x	
Nozzle cap nut		x		x						x				x		
Intermediate spindle			x		x	x				x						
Spring					x	x			x	x						
O-ring							x			x	x			x		
Dowel pin		x						x		x						
Adjusting nut and washer						x			x	x						x
Injector body	x	x		x	x	x	x	x	x	x	x	x	x		x	
Engine block	x							x		x	x					
High pressure pipe / inlet connector										x		x			x	
Drain pipe / leak off connector										x			x		x	
Combustion chamber				x				x						x	x	
Fuel oil		x	x							x		x	x	x	x	
Operator / maintenance engineer	x								x							x

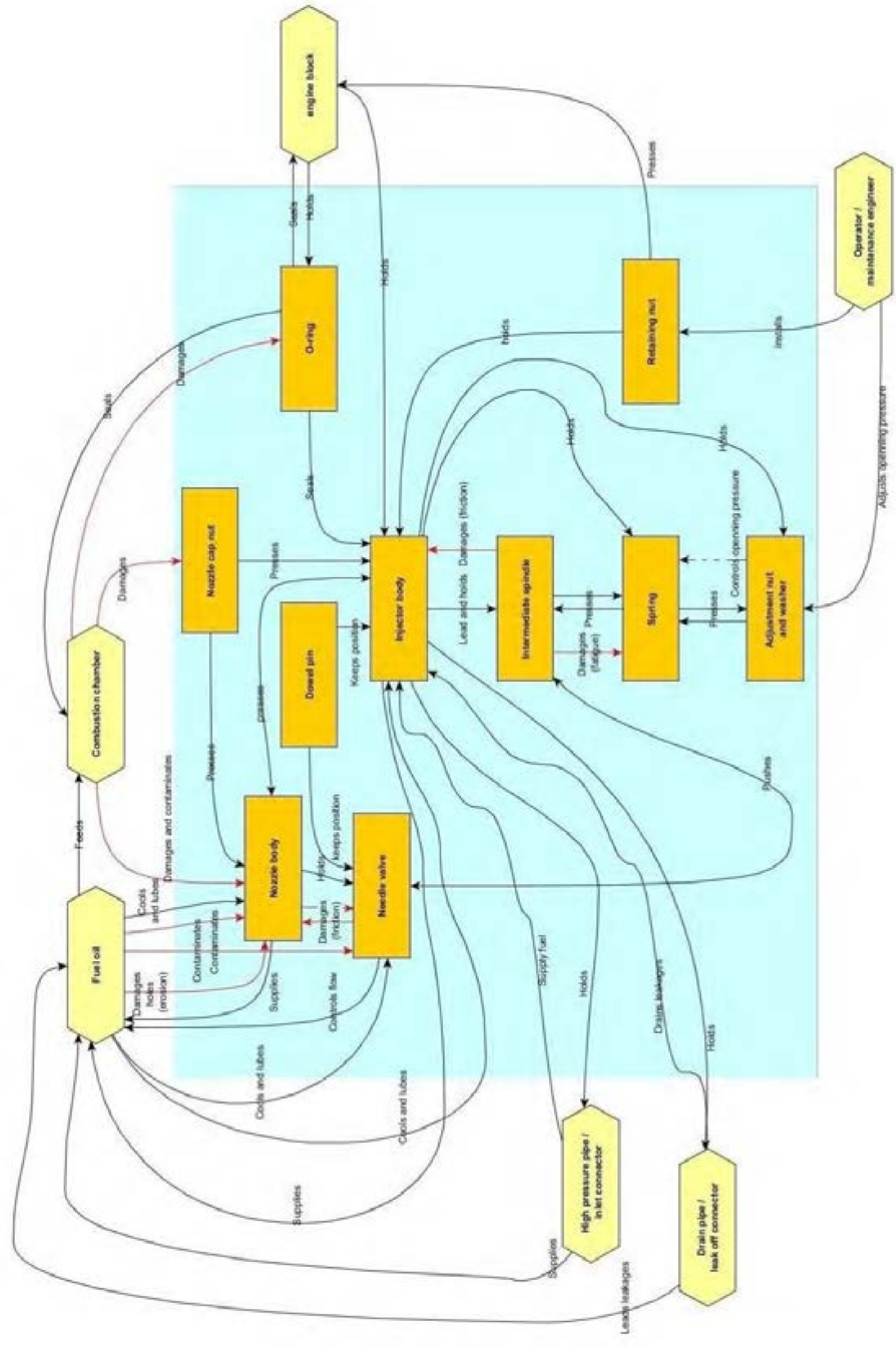

Fig. 3. Function model of the analysed system

4. Problem ranking

4.1. Single criterion analysis

For the analysed system, we have listed problems related to improper operation of particular components, then they have been compared mutually and summed their importance. The mutual relations have been classified as +1 when the given identified problem is more critical or correct (reliable and safe) achieving the objective function, and classified as -1, when it is less important, and 0, when problems are equally important. A summary of problems is presented in table 6. Generic analysis was carried out on the basis of expert opinions to present the methodology in this article [11, 12]. The first column also indicates denotations of individual problems, which will be used below in the paper.

Table 6

Comparative matrix of problems

Identified problem	Atomization holes are damaged by fuel erosion	Atomization holes are contaminated by carbon deposits from combustion	Needle valve stacked in nozzle due to fuel contamination	Excessive wear of precision pair (needle valve + nozzle body) due to	Contamination of the nozzle cap nut	Damage of the O-ring	Excessive injector body wear due to friction	Broken spring	Total score	Rank
R_h - Atomization holes are damaged by fuel erosion	0	+1	-1	+1	+1	+1	+1	-1	3	3
R_d - Atomization holes are contaminated by carbon deposits from combustion chamber	-1	0	-1	-1	+1	-1	+1	-1	-3	6
R_i - Needle valve stacked in nozzle due to fuel contamination	+1	+1	0	+1	+1	+1	+1	0	+6	1,2
R_f - Excessive wear of precision pair (needle valve + nozzle body) due to fuel contamination	-1	+1	-1	0	+1	-1	+1	-1	-1	5
C - Contamination of the nozzle cap nut	-1	-1	-1	-1	0	-1	0	-1	-6	7,8
O - Damage of the O-ring	-1	+1	-1	+1	+1	0	+1	-1	+1	4
B - Excessive injector body wear due to friction	-1	-1	-1	-1	0	-1	0	-1	-6	7,8
S - Broken spring	+1	+1	0	+1	+1	+1	+1	0	+6	1,2

The analysis showed that the potentially most important problems are: spring breakage and needle valve stacking in the nozzle due to fuel contamination, subsequently: atomization holes damaged by fuel erosion, O-ring damage and excessive wearing of precision pair.

4.2. AHP-based problem ranking

For the object analysis of the fuel oil injector, three importance criteria have been taken into account: safety, costs effectiveness and reliability. The criteria have been selected in a way that allow for the unification of their mutual evaluation. These characteristics were matched for the evaluation process with a goal of maximise:

1. Safety – understood as an inverse proportion of negative consequences for the system operation, connected with component failure – greater safety means lesser hazard for the staff, environment and the system itself.
2. Cost effectiveness – understood as a characteristic inversely proportional to system repair costs (spare parts, work force and system operation interruption costs) connected with the failure of a given component. Greater cost effectiveness means smaller restoration costs.
3. Reliability – certainty that the system will operate despite failure of a given component – greater reliability is connected with longer periods in between the planned maintenance work.

The mutual verbal evaluation of relations between criteria are created on the basis of the opinions given by specialists of the operation of technical systems. A mutual relevance matrix with generic data for the analysed criteria that has been created is presented in Table 7. The comparisons were prepared with the use of the fundamental scale applied for the AHP method described in section 2.

Table 7

Mutual relevance matrix for the analysed criteria

Parameters	Safety	Cost effectiveness	Reliability
Safety	1	3	6
Cost effectiveness	1/3	1	3
Reliability	1/6	1/3	1

C_I=0,0091 C_R= 0,0174 l_{max}=3,0181

After normalizing the matrix presented in Table 7, criteria relevance coefficients were obtained. These are shown in Table 8.

Table 8

Importance criteria relevance

Parameters	Sum	Weight	*A*
Safety	1,4999	0,6548	0,9821
Cost effectiveness	4,3333	0,2499	1,0828
Reliability	10,0000	0,0953	0,9530

It can be seen that in this case the parameter for safety equals over 65% of relevance, cost effectiveness 24%, while reliability is less than 10%.

The consistency ratio CR for the matrix equals 0,0174 and this allows the assumption that the matrix is consistent (value CR < 0,1 is required). The analysis can be continued.

The obtained results correlate with a common sense interpretation where safety is the most significant and reliability can be considered less important if the repair or component exchange costs are not high.

In the next step of the analysis, the relevance of the system components has been evaluated with regard to their influence on safe, low cost and reliable system operation. The relative mutual relations matrix of particular components according to the safety criterion is shown in Table 9. The comparisons were prepared with the use of the fundamental scale applied for the AHP method described in section 2. The following notations have been assumed (Table 6): Rh - atomization holes are damaged by fuel erosion, Rd - atomization holes are contaminated by carbon deposits from combustion chamber; Ri - needle valve stacked in nozzle due to fuel contamination; Rf - excessive wear of precision pair (needle valve + nozzle body) due to fuel contamination; C - contamination of the nozzle cap nut; O - damage of the O-ring; B - excessive injector body wear due to friction; S - broken spring. Consistency ratio C_R for the input data equals 0,0180 and it allows for the assumption that the matrix is consistent.

Table 9

Relative mutual relations matrix according to the criterion *safety*

Safety	R_h	R_d	R_i	R_f	C	O	B	S
R_h	1	1/4	2	1/3	1/5	1/2	1/5	2
R_d	4	1	5	2	1/2	3	1/2	5
R_i	1/2	1/5	1	1/4	1/6	1/3	1/6	1
R_f	3	1/2	4	1	1/3	2	1/3	4
C	5	2	6	3	1	4	1	6
O	2	1/3	3	1/2	1/4	1	1/4	3
B	5	2	6	3	1	4	1	6
S	1/2	1/5	1	1/4	1/6	1/3	1/6	1

C_I=0,0252 C_R=0,0180 l_{max}=8,1765

Table 10 presents the relative mutual relations matrix of particular components according to the cost effectiveness criterion. The comparisons were prepared with the use of the fundamental scale applied for the AHP method described in section 2. Consistency ratio C_R for the input data equals 0,0068 and it allows for the assumption that the matrix is consistent.

Table 10

Relative mutual relations matrix according to the criterion *cost effectiveness*

Costs	Rh	Rd	Ri	Rf	C	O	B	S
R_h	1	1	1	1	3	4	1/2	2
R_d	1	1	1	1	3	4	1/2	2
R_i	1	1	1	1	3	4	1/2	2
R_f	1	1	1	1	3	4	1/2	2
C	1/3	1/3	1/3	1/3	1	2	1/4	1/2
O	1/4	1/4	1/4	1/4	1/2	1	1/5	1/3
B	2	2	2	2	4	5	1	3
S	1/2	1/2	1/2	1/2	2	3	1/3	1

C_I=0,0095 C_R=0,0068 l_{max}=8,0665

Table 11 presents a relative mutual relations matrix of particular components according to the criterion reliability. The comparisons were prepared with the use of the fundamental scale applied for the AHP method described in section 2. Consistency ratio C_R for the input data equals 0,0122 and it allows for the assumption that the matrix is consistent.

Table 11

Relative mutual relations matrix of components according to the criterion *reliability*

Reliability	R_h	R_d	R_i	R_f	C	O	B	S
R_h	1	1	1	1	6	3	9	3
R_d	1	1	1	1	6	3	9	3
R_i	1	1	1	1	6	3	9	3
R_f	1	1	1	1	6	3	9	3
C	1/6	1/6	1/6	1/6	1	1/3	3	1/3
O	1/3	1/3	1/3	1/3	3	1	6	1
B	1/9	1/9	1/9	1/9	1/3	1/6	1	1/6
S	1/3	1/3	1/3	1/3	3	1	6	1

C_I: 0,0171 C_R: 0,0122 l_{max}=8,1194

After normalizing matrices 4-6, relevance parameters, of given components, were obtained according to the selected criteria as shown in Table 12. The following notations have been assumed: Rh - atomization holes are damaged by fuel erosion, Rd - atomization holes are contaminated by carbon deposits from combustion chamber; Ri - needle valve stacked in nozzle due to fuel contamination; Rf - excessive wear of precision pair (needle valve + nozzle body) due to fuel contamination; C - contamination of the nozzle cap nut; O - damage of the O-ring; B - excessive injector body wear due to friction; S - broken spring.

Table 12

Components relevance according to the selected criteria

Criteria preferences	Safety	Costs	Reliability
R_h	0,0492	0,1444	0,1989
R_d	0,1722	0,1444	0,1989
R_i	0,0324	0,1444	0,1989
R_f	0,1139	0,1444	0,1989
C	0,2624	0,0520	0,0332
O	0,0750	0,0351	0,0769
B	0,2624	0,2527	0,0176
S	0,0324	0,0824	0,0769

It should be noticed that according to the criterion ‘safety’, B and C (with over 26% relevance) are the most significant system components/problems as well as R_d and R_f (over 17% and 11% relevance relatively). The influence of other components on the system operational safety is relatively little – below 7%. According to the criterion ‘cost effectiveness’, B (with over 25% relevance) is the most significant system component. According to the criterion ‘reliability’ nozzle body and needle: R_h, R_d, R_i and R_f (with over 19% relevance) are the most significant system components/problems.

The last part of the analysis is to indicate an aggregated measure describing the system components relevance, considering all the criteria simultaneously. Table 13 shows the multi-criteria ranking of the components importance.

Table 13

Multicriteria ranking of components importance considering all the criteria

Alternatives rankings with structure	Safety	Costs	Reliability	Result	Rank
R_h	0,0322	0,0361	0,0190	0,0873	5
R_d	0,1128	0,0361	0,0190	0,1678	3
R_i	0,0212	0,0361	0,0190	0,0763	6
R_f	0,0746	0,0361	0,0190	0,1296	2
C	0,1718	0,0130	0,0032	0,1880	2
O	0,0491	0,0088	0,0073	0,0652	7
B	0,1718	0,0631	0,0017	0,2366	1
S	0,0212	0,0206	0,0073	0,0491	8

The aggregated relevance evaluation shows that B and C, with a relevance over 23% and 18% respectively, are the most significant system components, considering all the criteria.

5. Discussion

Summary of the results obtained, for each criterion, indicates convergence of the safety criterion grades (assessments). In the presented single-criterion analysis the assessment was based on the consequences of problems during the proper use of the object. The following notations have been assumed (Table 6): Rh - atomization holes are damaged by fuel erosion, Rd - atomization holes are contaminated by carbon deposits from combustion chamber; Ri - needle valve stacked in nozzle due to fuel contamination; Rf - excessive wear of precision pair (needle valve + nozzle body) due to fuel contamination; C - contamination of the nozzle cap nut; O - damage of the O-ring; B - excessive injector body wear due to friction; S - broken spring. Figure 4 shows the ranking of individual problems for the particular criteria in the AHP method and in the single criterion analysis. In order to compare the used methods, the values for the single-criterion analysis shown in figure 4 were determined after normalization and re-scaling to the total score range of <0.0; 2.5> from table 6.

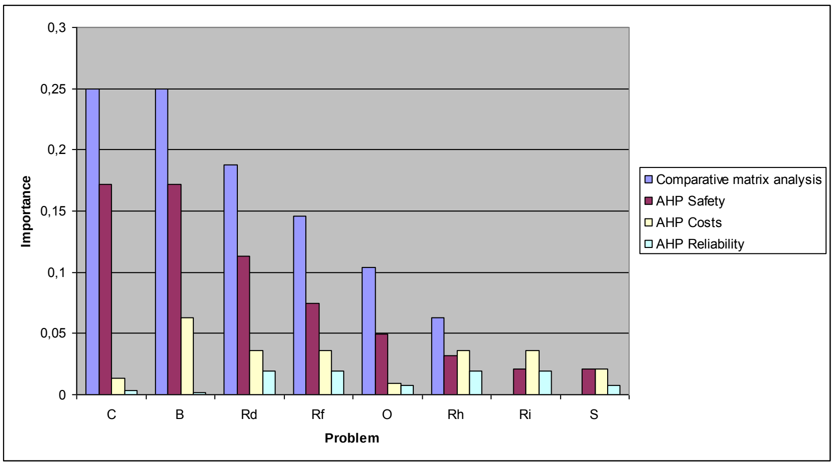

Fig. 4. The importance of individual problems in terms of single criterion

In view of varying weights of the individual criteria and varying partial rankings, the final ranking obtained in the analysis based on the comparison matrix and final ranking from the AHP method differ significantly (Figure 5).

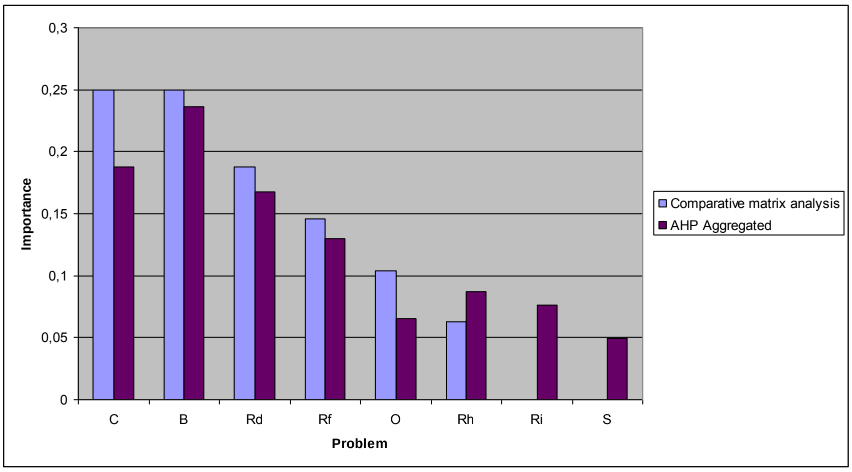

Fig. 5. The final importance of individual problems as determined with different methods

6. Final conclusions

Utilization of AHP as a tool for evaluating problems in the TRIZ function analysis is advantageous owing to simultaneous determination of criteria ranking and problem ranking. Moreover, the method allows one to change the severity of interrelationships of each problem, which increases the suitability of such an approach for analysis of complex systems with varying the severity of effects of hazards associated with the operation of the given system.

The article presents an analysis for safety, reliability and cost effectiveness criteria. The number of criteria can be arbitrarily increased depending on the purpose and scope of the performed function analysis [14]. For the example given the following issues could also have been analysed: availability of spare parts, system repair time, and ergonomics of operation or even aesthetic values for the user of the system.

Using the AHP method requires the calculation of the consistency ratio C_R every time which makes it possible to simultaneously evaluate the mutual relations matrix obtained on the basis of expert opinions. In addition, for calculating the consistency ratio C_R, average expert opinions are considered [7]. When CR is too high, obviously there are some conflicts in the analysed data which can be corrected at the start.

AHP analysis can be used to associate the quality parameters of the system performance (defined by experts) with quantitative parameters based on statistics or measurements. With the results obtained, it is possible to use additional TRIZ tools to solve problems having the highest rank, including through [2, 15, 16]:

- application of inventive principles and 76 inventive standards;
- conducting an in-depth analysis of the causes of the problem using root conflict analysis (RCA+) or cause and effect chain analysis (CECA) and then application of ARIZ algorithm to solve the problem;
- the use of the directory of physical, chemical and geometric phenomena to achieve the desired function of the system if the problem cannot be solved with common scientific principles;
- analysis of resources and system trimming (removing selected components and sharing the functions of other components without lowering of overall functionality, quality and efficiency of the system).

As the proposed analysis might be perceived as more difficult than the comparative matrix, to make the whole analysis easier the AHP analysis can be supported by a computer software. There are many computer programmes and on-line tools available, some of them are free of charge, e.g. Super Decisions (https://www.superdecisions.com/) or 123AHP (http://www.123ahp.com).

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AN IMPROVEMENT FOR EXISTING FUNCTION APPROACH

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Abstract

After studied and researched on the existing function model methods, this paper has figure out a disadvantage in existing function model as well as the adverse effects in real invention practice.

After then, the author introduced a new symbol to improve the intuition of the function model. Eventually, a new function model has been proposed in the article, following by a real example to show the details of improved function model.

Keywords: Function Modelling Approach, Function Model, Hourglass, Improved Function Model

1. Introduction

As a problem description tool, function analysis and approach takes a very important role in modern TRIZ system. See Fig.1. An accurate, correct and intuitive system function model could be used in the subsequent stages of the analysis: Flow Analysis, Cause-Effect Chain Analysis (CECA) or Root-Cause Analysis (RCA), Trimming, Feature Transfer. Super Effect Analysis [2], Etc.

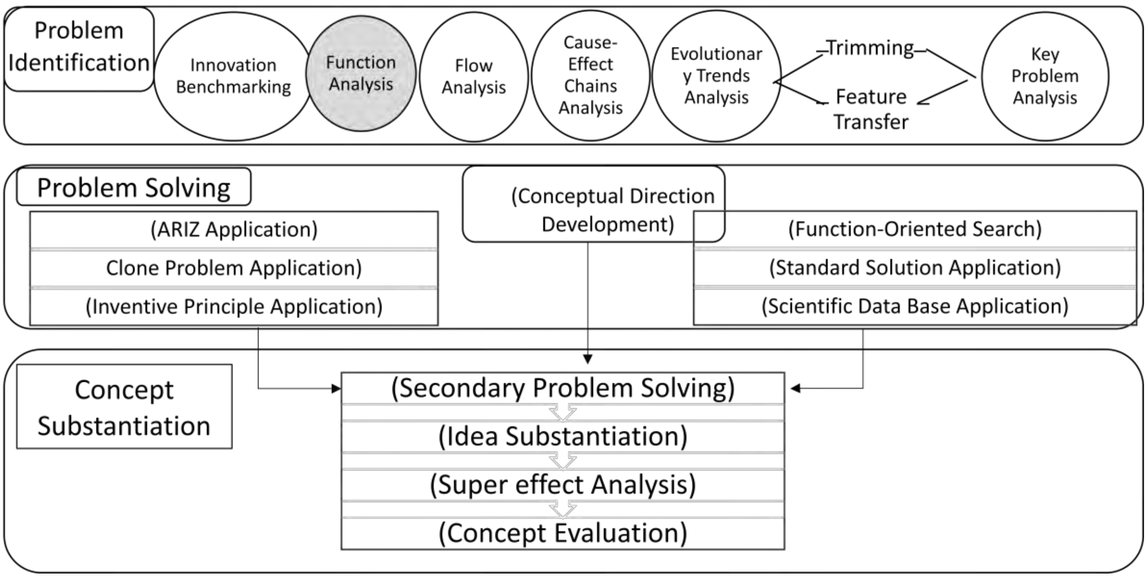

Fig. 1. Modern TRIZ Architecture [1]

According to “TRIZ the Golden Key to Open the Gate of Innovation” [3], three steps are needed to do for function analysis and modelling. They are Step 1, the components analysis, step 2, the interactive analysis and step 3, drawing the function model. Fig. 2 is a function model made by these steps.

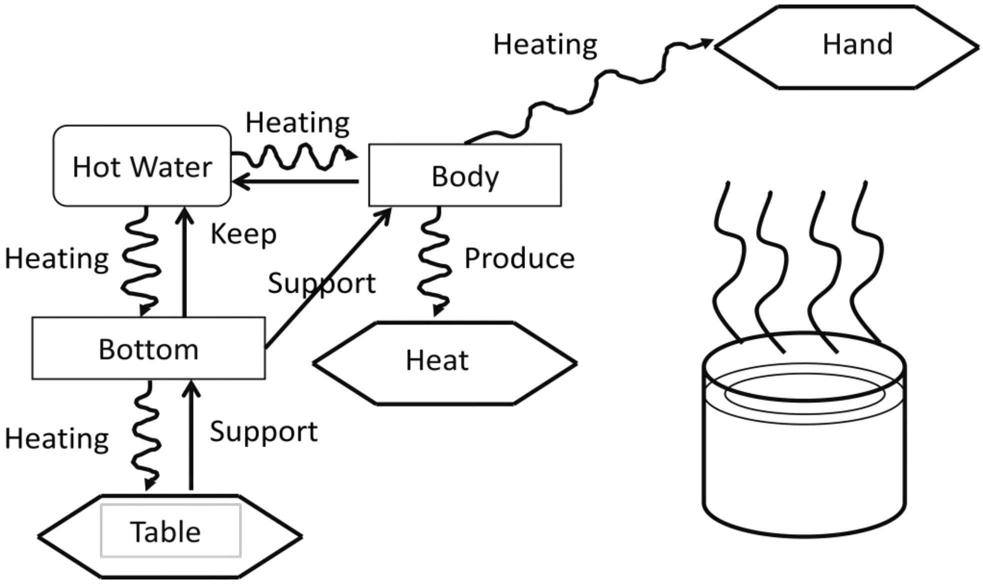

Fig. 2. The Function Model of a Cup with Hot Water [3]

2. The Disadvantages of Current Function Approach

On the basis of Simon Litvin, Naum Feygenson, and Oleg Feygenson's "Advanced Function Approach" (AFA) [2]. The spatio-temporal parameters have been suggested into the old function approach and a table with spatio-temporal parameters was introduced. A table based on the approach has been generated for the cup with hot water. Show in Table 1.

Table 1

AFA Table for a Cup with Hot Water function approach

Time	Function			Type and level of performance	Location	Comments
	Function Carrier	Action	Object of Function			
10	Water	Heat	Body	Harmful	Bottoms Up	
20	Body	Heat	Hand	Harmful	Bottoms Up	
30	Body	Keep	Water	Basic, Normal	Whole Surface	
40	Body	Transfer	Temperature	Harmful	Bottoms Up	
50	Water	Heat	Bottom	Harmful	Whole Surface	
60	Bottom	Keep	Water	Basic, Normal	Whole Surface	
70	Table	Support	Bottom	Basic, Normal	Contact Surface	
80	Bottom	Heat	Table	Harmful	Contact Surface	

The table 1 is very helpful to identify the cup system's disadvantages, excessive cost of components and, the wrong place and time of performing functions, and the absence of the required functions, but it is not enough for it is not intuitive and convenient sometimes. It is necessary to improving the existing function approach and an intuitive and convenient function model is useful to TRIZ practice.

3. An Improvement of Current Function Model

In order to improve the intuitionism and convenient of the current function model, a symbol of hourglass shape has been taken which is as the new sample to replace the existing symbol of a component in function model. Show in Fig. 3. With this new symbol, the position of the end of an arrow line has defined the occurring time of a function. The upper point of the hourglass, arrow 1, represent the function will be effective at the beginning time, the middle one , arrow 2, represent the function will be effective at the middle time, and the bottom one , arrow 3, represent the function will be effective at the post time. People could make their own choose during the function approach. The Type and level of performance of a function is kept in the same as the existing function approach.

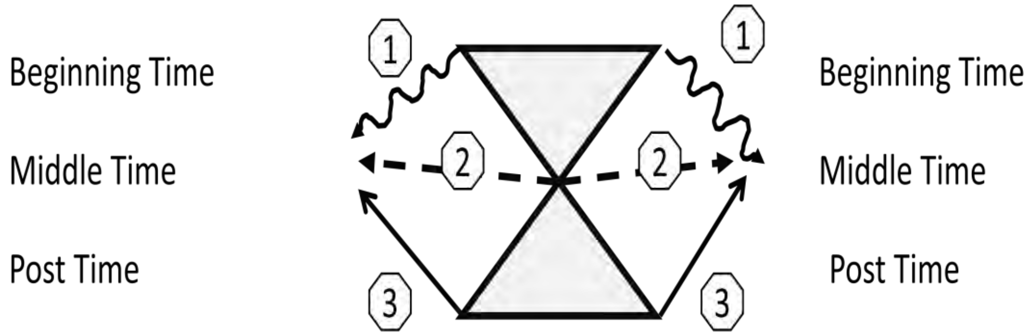

Fig.3. New Symbol for Component in Function Model

With above improving, a new function model of a cup with hot water is shown in Fig.4.

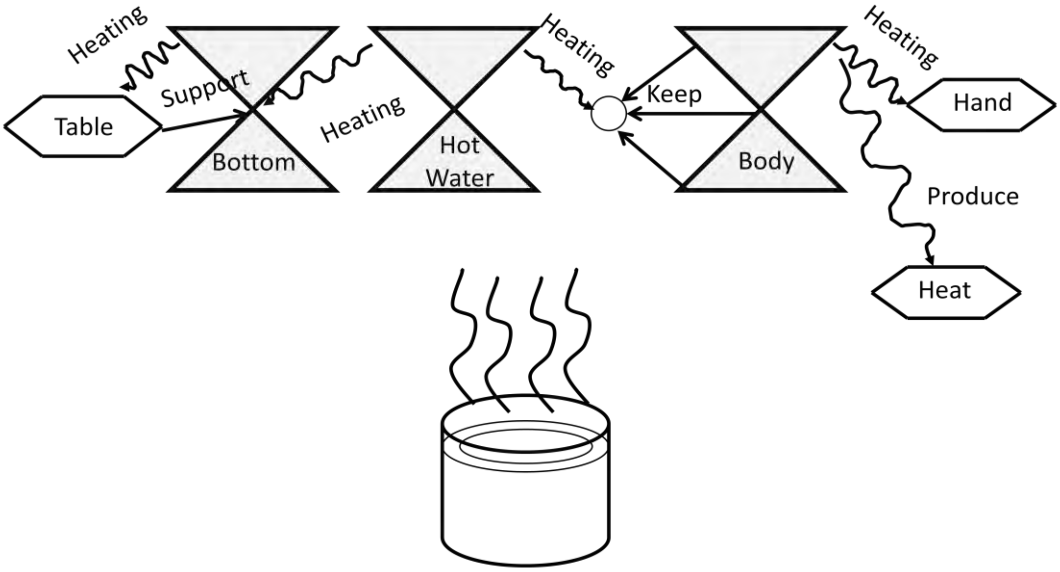

Fig. 4. New Function Model of a Cup with Hot Water

In Fig.4, people could easily and intuitive figure out the problems which need to be solved. They are: 1. Hot water heat the bottom at the beginning (When the water is very hot), 2. The bottom heats the table at the beginning, 3. Hot water heats the body at the beginning. 4. The body will generate the heat at the beginning and heat the hand when people touch the body which means the action is driven by event. Here the select problems need to solved are of objective for they are just picked up from the graph of a function model directly.

4. A Real Example with Improving Function Model

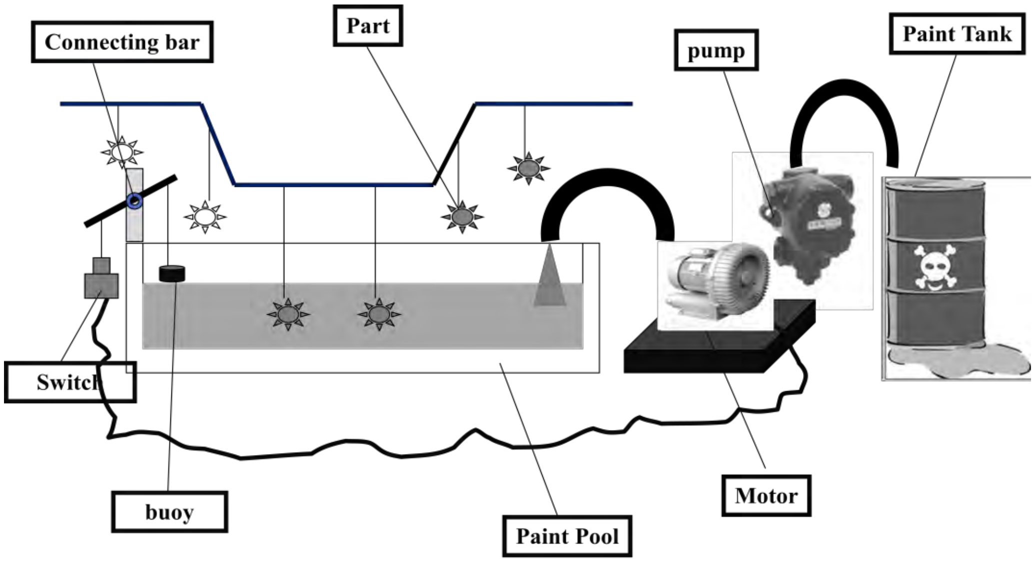

Fig.5. Painting Unit [1]

Fig. 5. shown a painting unit in an automotive manufacture line, the normal production process is: The parts which need to be painting are moved by hanging rail and then go down to the paint pool to paint. When the paint oil is not enough, the buoy will move the connecting bar to control the switch to turn on the motor, and the motor will drive the pump to push the paint. Here the problem is that the paint surround the buoy will adhered the surface of the buoy for the air's dry effect, which will lead the buoy always keep in the lower position and the switch will always turn on, finally, the paint will full of the paint pool and go out into workshop's floor everywhere.

According the above problem situation, a traditional function model could be built as shown in Fig. 6.

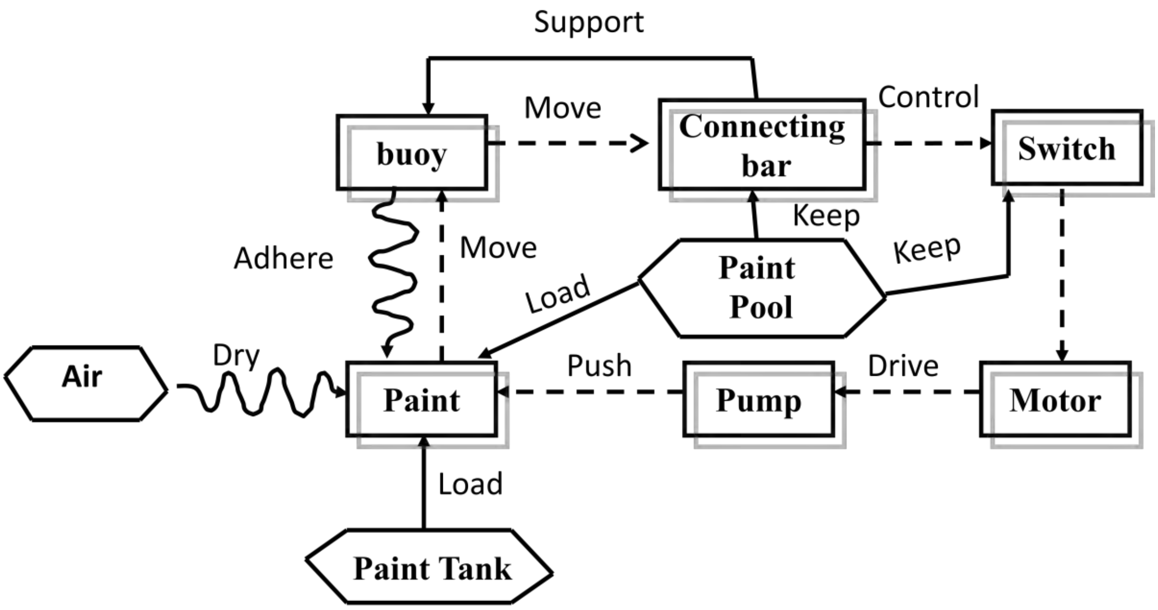

Fig. 6. The System function Model of a Painting Unit [1]

Based on Fig.6., the select problems need to be solved could be as following [3]:

1. Buoy could not move the connect bar effetively;

2. Buoy adhere the paint;
3. The connect bar can not control the switch effetively;
4. The switch can not control the motor effetively;
5. The motor could not drive the pump effetively;
6. The pump could not push the paint effetively;
7. The paint could not move the buoy effetively;
8. Air adhere the buoy.

It is clearly that the most of the problems in above will not happened in the beginning. But within existing function model, people did not have effective and intuitive way to describe them.

An improved function model is shown in Fig.7. In this new function model people could easily figure out the core problem “How to prevent the buoy from drying by air in the working period” for the model is intuitive with function occurrence time in the graph.

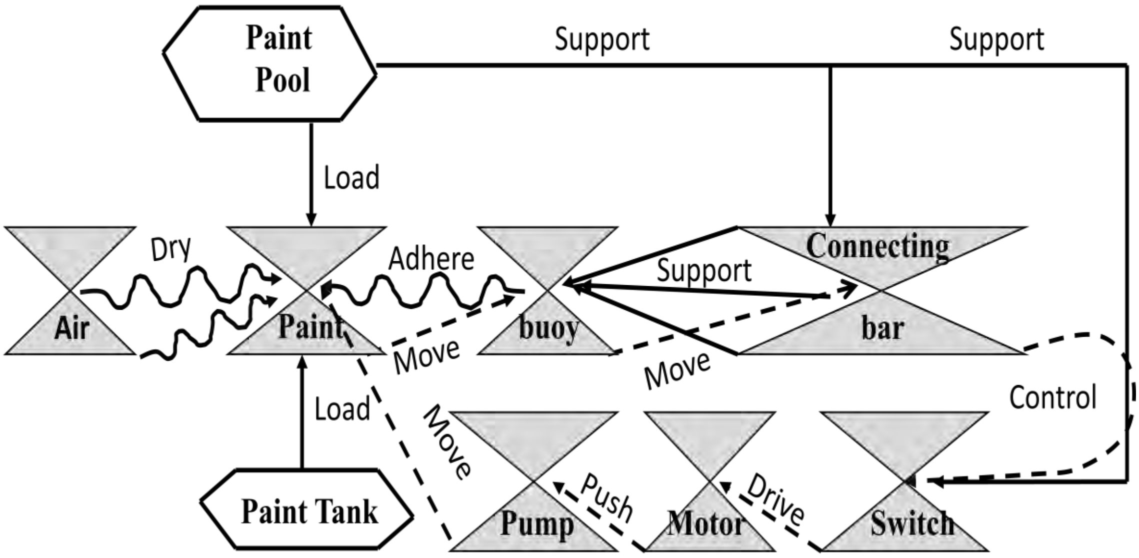

Fig. 7. An improved function model

5. Conclusions

“If I had one hour to save the world, I would spend the 45 minutes to analyze the problem, 10 minutes to review it and 5 minutes to solve it!” ----Albert Einstein.

Describing the problems situation in objective and express intuitive is the key starting point in TRIZ practice. This paper has revealed the disadvantage of the existing function model and furthermore, proposed a new function model with new symbol, the author hope the new function model will be helpful to figure out the latent core problems in the engineering situation with more objective and more intuitive.

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APPLICATIONS OF TRIZ IN BUSINESS SYSTEMS

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Abstract

This article describes application of TRIZ to solving inventive problems that we face while implementing projects for customers at EPAM Systems – a company that provides services for global product development and digital platform engineering.

Basing on our practical experience, we consider the nature of inventive problems typical for business systems and discuss the most efficient TRIZ tools and other adjacent tools to use for identification and solving such problems.

Keywords: business system, inventive problem, opportunity map, RCA, contradiction, ARIZ.

1. Introduction

Technology evolution drives development of our civilization. More and more new engineering systems are entering our life to solve our problems creating a completely new experience. This new experience, in turn, results in new needs and related problems, which requires next systems to be developed.

To improve our life with a new engineering system is not enough just to build it. Many people should get access to the system and use it in their everyday life. This is the business, who solves the task of scaling the invented solution and delivers it to people as products (goods and services).

At the dawn of the civilization development, the task of scaling was solved by goods manufacturers, and merchants who delivered goods to remote regions of the Earth. Today, the task of scaling is solved by companies and organizations: from individual entrepreneurs and small companies that conduct their business in a small area (on the street or in the city), to transnational corporations such as Amazon, Google, Tesla Motors, which operate globally and constantly are in contact with their Consumers all over the world.

In this article, we consider business systems as systems consisting of companies and organizations manufacturing and marketing products (goods and services), buyers who purchase and use these products and market relations between companies and buyers, built on a free exchange of values [1]. The creation of new and the improvement of existing business systems often requires solving of inventive tasks, where the use of standard solutions is impossible or insufficiently effective.

We are presenting EPAM Systems. Since 1993, EPAM Systems, Inc. (NYSE: EPAM), has leveraged its core engineering expertise to become a leading global product development and digital platform engineering services company.

Our customers often come to us with requests that require not only the development of some solution, but also the solution of complex tasks related with the development of their business. In this case, the problems can be formulated generally; the solution of such problems involves the analysis of the client's business system, the identification of a large number of requirements from different stakeholders. Usually such an analysis leads to contradictions, which converts such problems into the category of inventive problems [2].

In this article, we will share our experience of identifying and solving inventive problems, which we faced within the projects at EPAM Systems. In addition, we will present examples of the use of TRIZ tools, which we apply in our practice.

2. Transition from Engineering System to Product

Engineers and inventors during the Engineering System (ES) development traditionally deal with already defined requirements for the system. Research activities users' behavior, experience of using ES in specific (often, very different) conditions goes beyond the scope of the engineer; this is the work of marketers, UX researchers, industrial designers and interface designers, business analysts, and product managers who coordinate this activity and make decisions about System requirements.

Usually product is oriented to be used in different solutions by different customers. Figure 1 shows diagram of ES, which performs some useful function – F on objects 1 and 2 (O1 and O2). This system is used by different customers - Customer 1 and Customer 2 in scope of different solutions - Solution 1 and Solution 2 for achieving customer goals, defined as Value 1 and Value 2. In Solution 1- Customer 1 performs actions - A1 and A2, in Solution 2 - Customer 2 performs actions A3, A4 and A5, but at the same time, Customer 2 is using additional ES.

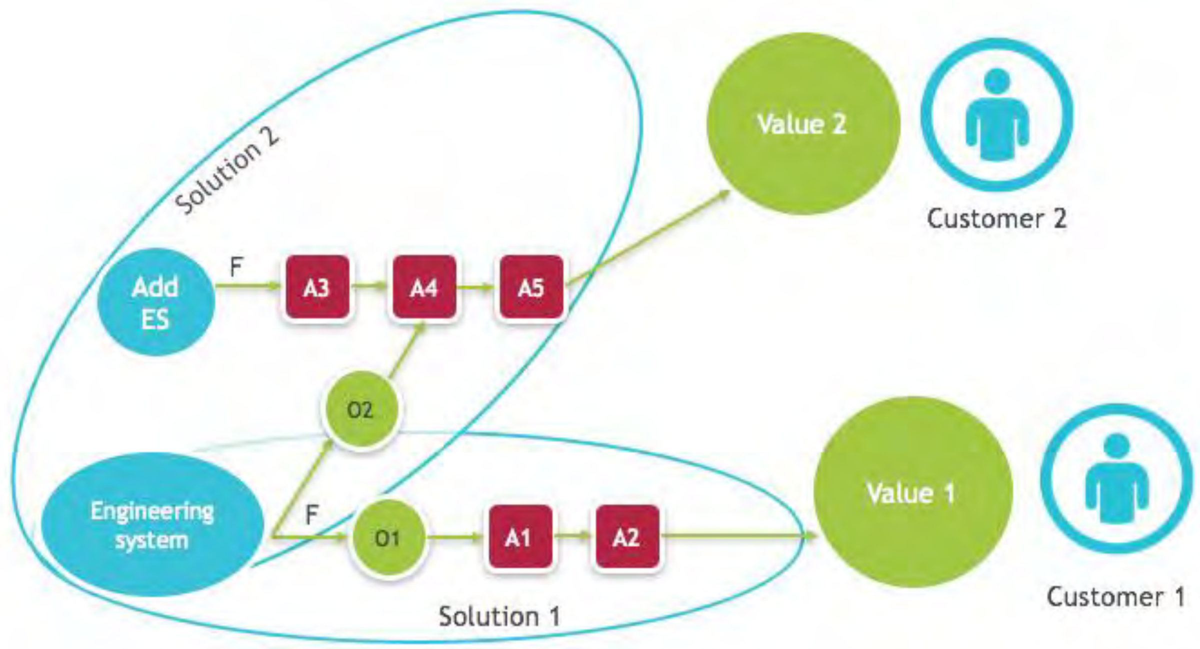


Fig. 1. Usage of engineering system in different solutions by different customers.

Because of using the product, User reaches the goal expecting to receive certain benefit. In fact, these expectations are the source for the requirements to the engineering system which underlies the product. In this case, the user is the main source of uncertainty of the requirements. Unlike functions within the engineering system, which parameters can be definitely described, the parameters of human interaction with engineering systems are much more difficult to describe. This is the reason for rising uncertainties in the description of the business system.

A big number of different users of the product is a kind of multiplier of this uncertainty. The product must meet the requirements of a big number of users with different wishes, needs and understanding of the value that they want to receive from using the product.

3. Transition to Business System

Business system is a system consisting of companies and organizations that produce and sell products (goods and services), consumers who purchase and use these products and market relations between companies and consumers, built on a free exchange of values [3].

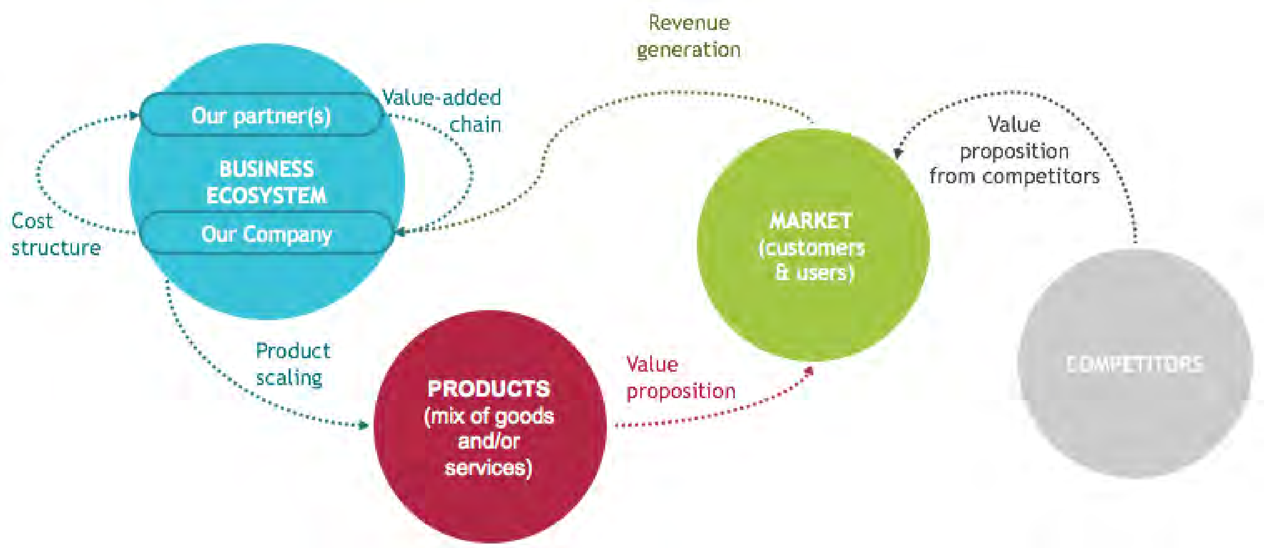


Fig. 2. Business-system

Business system produces value for stakeholders, including ultimate customers. In the most simplified version business system structure can be presented as illustrated on Figure 2. Business system includes various engineering systems that implement functions necessary for useful work of the business system.

The main components of the business system [4] are as follows:

- Market which consists of lots of consumers and users of the product represented by the business system as well as competitors and their products;
- Product itself, which is created and produced in the business system and delivered to the consumers, including additional services;
- Business ecosystem, which includes one or more companies which interact with each other within a single value chain, creating, producing and delivering the product to consumers.

An essential feature of business system is a big number of stakeholders. Except product users, business system includes customers (who are not always users of the product), business stakeholders (business owners, managers and employees), as well as society, the state, etc. Different stakeholders have different interests, which also need to be investigated and accounted within the business system.

One of the key functions of the business system is scaling of the value for a big number of users of products which are produced within the business system, as well as other stakeholders. In this case, scale plays a role of multiplier not only for the value, but also for any undesirable effects that occur in the business system.

4. Invention Problems in Business System

Per research [6], conducted for 150+ business models, an inventive problem containing a contradiction may arise in different components of the business system: consumer markets, product, companies entering the business ecosystem, and interactions between components of the business system.

Usually Client comes with a complicated problem especially in the cases when he has already made attempts to solve it and received unsatisfactory results. Information that the Client comes with, may contain results from early attempts to solve it, or may not contain such information. Solution for the problem is still actual for the Client, as this solution can have significant impact on his business.

At the first stage, we are performing research of the Client's business system in general and clarifying components of the business system that relates to the Client's problem. For this stage, we use several analytical tools from service design [5] approach and business analysis like:

- Investigation of the value proposition [6]
- Research of the business ecosystem [7]
- Business Process Analysis AS IS [8]

4.1 Value Proposition Analysis

One of the EPAM Clients – US online Car Information Aggregator. Aggregator Portal with a set of accompanying mobile apps includes prices for new and used vehicles, dealer and inventory listings, a database of national and regional incentives and rebates, vehicle test drive reviews, and tips and advice on all aspects of car purchases and ownership. Company looked for strategy forming for the next years and asked EPAM for recommendations in this field.

Analyzing the value proposition, we use the Osterwalder's Value Proposition template, which is presented on Fig.3 (Customer Profile with gains and pains) and Fig. 4 (Product value map with gain creators and pain relievers) for the Client Portal.

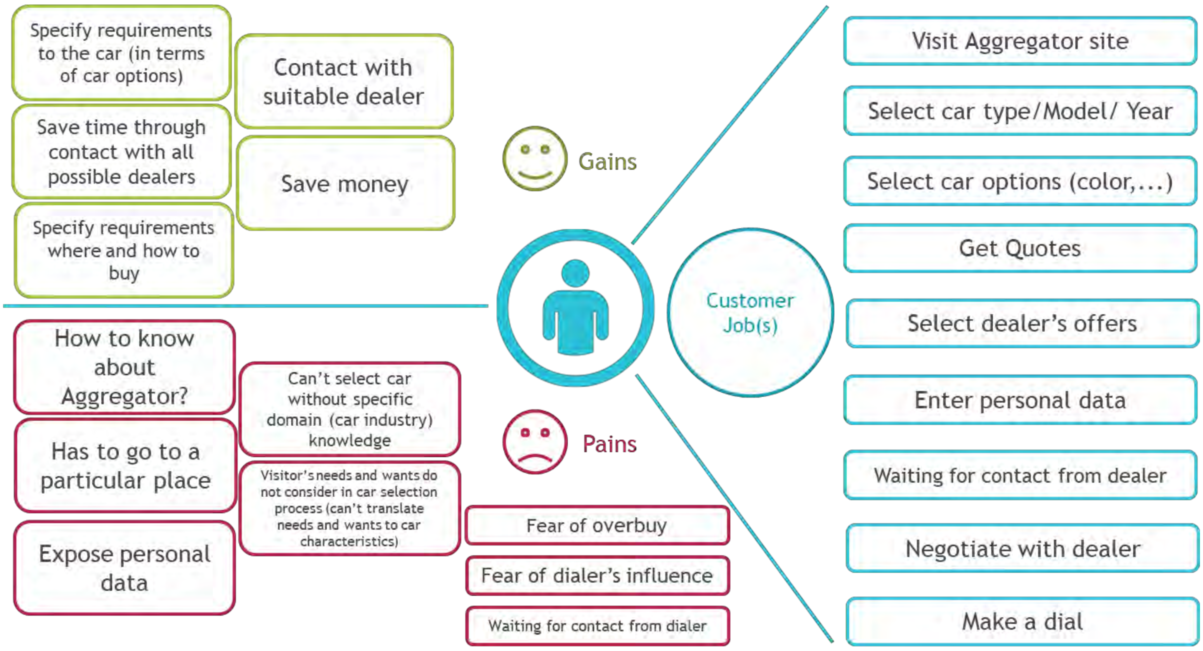


Fig.3. Value Proposition Model: Customer Profile

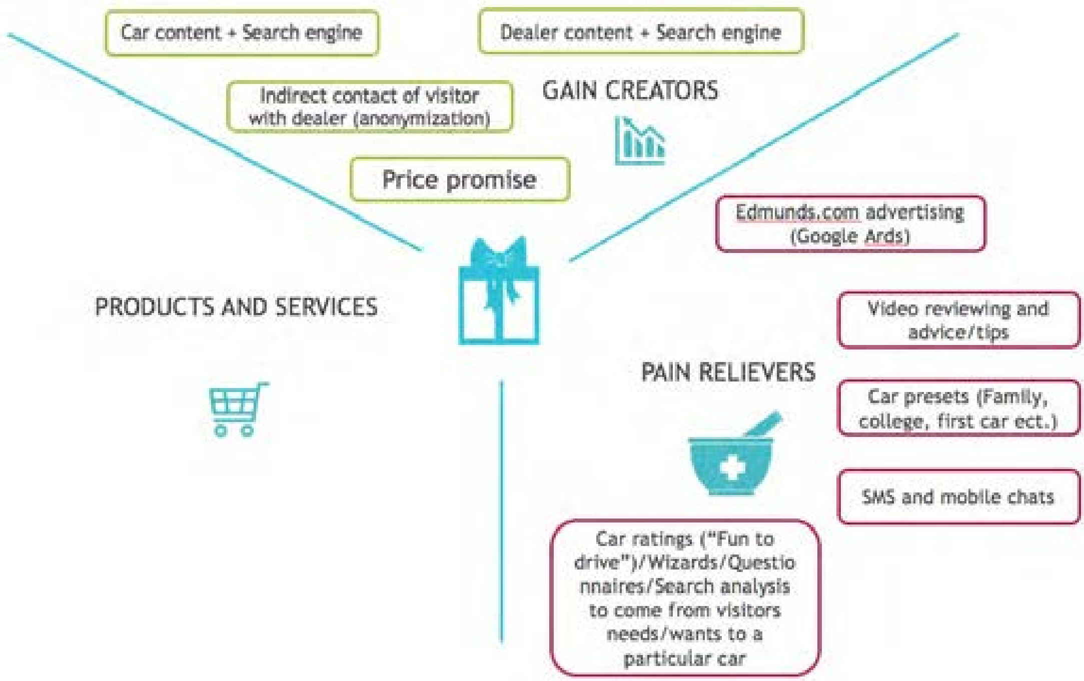


Fig. 4. Product Value Map

The Value Proposition template allows to understand Consumers and the value they expect from our product, on one hand, and to understand how our product allows the Consumer to receive the value, on the other hand.

Purpose of analyzing the Value Proposition is identifying gaps between Gain Creators and Gains, on the one hand, Pains and Pain Relievers, on the other hand.

As a result, we get a list of Gaps for the product which need to be fixed. Gaps are potentially sources of inventive tasks. Thus, because of the further analysis we identify number of inventive problems. They are presented in the table on Fig. 5 in the form of contradictions:

Known solution	Requirements	Negative Effects
Dialog with visitors	• allows to get info about visitor`s needs and wishes • Make visitor more happy and informed about what car he/she needs	• Visitor have to spend a lot of time and efforts • Decreases dealer margin due to buyer know what car he/she needs
Creation of car classificatory based on needs and wishes	• allows to select car without domain specific knowledges • increase conversion of visits to leads	require to develop this classificatory (hard and time expensive process)
Closing of visitor's needs and wishes for dealer	compliance with the broker's law	dealer will have not information about buyer (visitor) requirements
Opening of visitor's needs and wishes	Make visitors more happy and increase conversion of visits to leads	Decreases dealer margin due to buyer know what car he/she needs
Usage of proxy during contact of visitor with dealer	Defenses visitor from dealer's spam	• Visitor have to wait the respond from dealer • Creates delays in communications
Auction for hot leads	Increases Edmunds revenue from leads	Dealers have to pay for leads not for deals

Fig.5 Table with List of Contradictions

4.2 Business - Ecosystem

Our client was a company that produces coffee machines and drink packs. These machines are installed in offices. Our client needed to collect detailed drinks consumption data to better plan production and development of new products. Distributors of our client's drinks either did not have detailed data or did not want to share it with drink producer. Then our client came up with an idea to connect the coffee machine and directly collect consumption data. However, the they faced the following issue: the office owner did not allow to connect the machines to the company network, while installing a separate GSM modem into the machines was too expensive.

We analyzed the value chain (see Fig. 6) and identified the following contradiction. Our client produces tons of different flavors of drinks. The merchandizer, that is placed next to the coffee machine can store limited number of different flavors. As it is too much effort for the machine owner to collect individual preference of the office employees it orders predetermined sets of flavors. Employees would like to have specific flavors at their machines, but only can ask the machine owner to switch for another predetermined set, which would not fit the all employees' preferences either.

We proposed to create a new additional value for the consumers and let them select drinks, that are supplied to their machine. Moreover, we proposed to exchange this additional value for communicating consumption data through the consumer`s personal devices. The proposed solution is based on using an application, which is loaded to consumer's phone and allows the consumers to order their favorite drinks to be available at the machine they are using. The machine identifies the consumer when he or she approaches it by communicating with the application through Bluetooth connection. The consumer data accumulated in the machine is passes through the application directly to our client.

This win-win solution gives value both to the consumers as they are now able to select exactly what they want to have in their machine and to drink producer as it gets a direct communication channel with its clients (see Fig. 6). Also, the machine owner does not have to care about selection of supplied drinks any more.

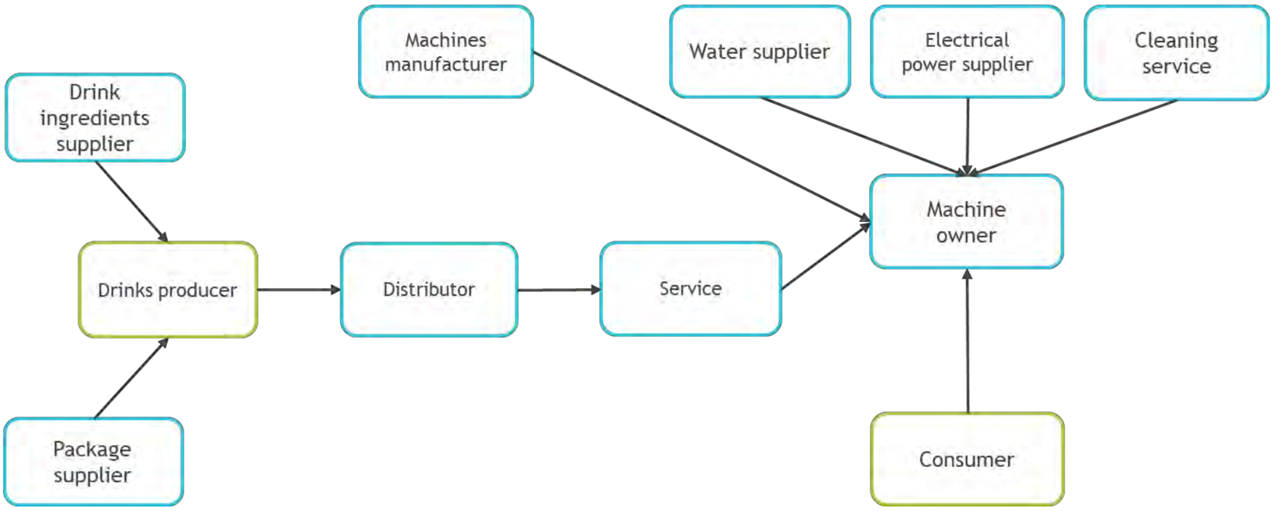


Fig. 6. Simplified value chain for the current of coffee machine business.

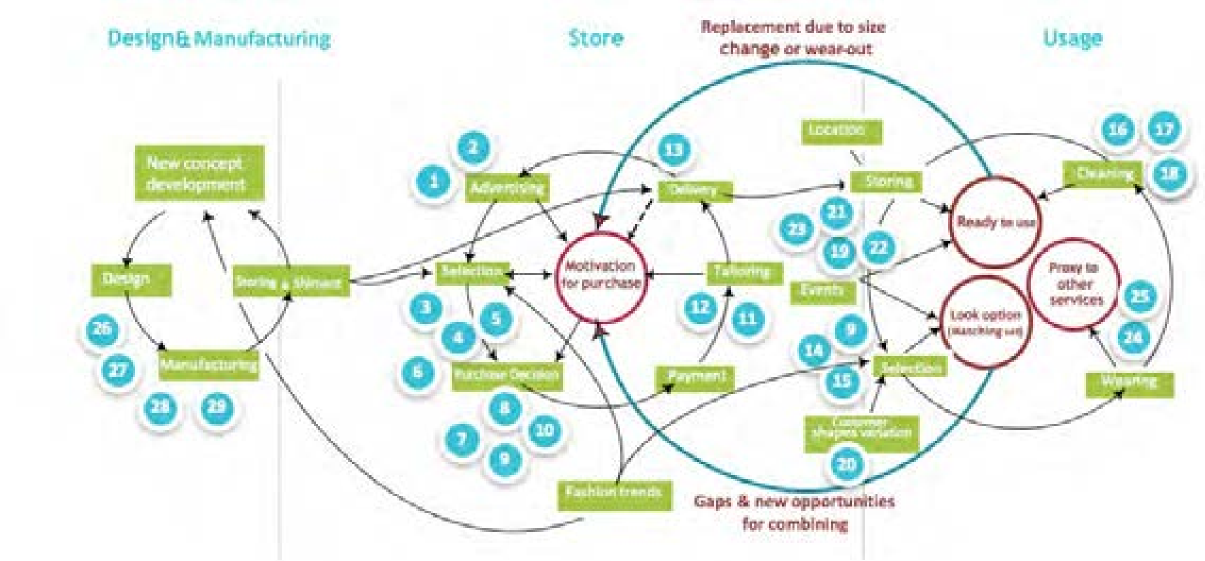
Analyzing the relations between participants of the business ecosystem makes it possible to identify the various flows that exist in the business system, including the flows of raw materials and products, information and financial flows.

The purpose of analyzing flows in the business ecosystem is to identify "bottlenecks" and negative effects, which in their turn are the sources of inventive tasks.

4.3 Opportunity Map

Another EPAM Client – World famous garment brand came with request to fix problem with logistics and number of returns. It turns out that sizes of the same clothing item may differ depending on the fabric where it was manufactured. And again, before diving into the solving of this problem, we analyzed business system in general, but from another point of view.

During business system (BS) analysis we detected challenges, problems, gaps, undesirable effects and etc… As the next step, we execute impact analysis and prioritization and define what problems have the biggest influence on company`s business. As an outcome of the process, so called “opportunity map” (you can see example of such Map on Fig. 7) was created.



1. 360 degree show
2. Virtual store
3. Style adviser
4. Holo-fitting
5. Body tracking
6. Size detection
7. Friend’s approval
8. Chatbot
9. Virtual try-on
10. Self-360 degree view
11. 3D models for tailoring
12. Adjusted clothes
13. Actual clothes size detection
14. Style adviser
15. Integrated fashion trends
16. Time-adjusted cleaning service
17. Customized cleaning service adjusted to clothes design and conditions
18. IoT to set cleaning conditions
19. Planned appearance
20. Size variation detection
21. Event tracking
22. Virtual closet
23. Weather tracking
24. Profile storage
25. Priority storage
26. Customized fit
27. Customized printing
28. Limited editions/series
29. Designed by customer

Fig. 7. Opportunity Map

5. Using TRIZ tools to identify and solve inventive tasks.

The statistics based on our projects shows that in about 80% of cases it is enough to formulate the right problem and use known solutions. In the remaining 20% - we encounter a problem that contains contradictions, that is, an inventive task. Often to eliminate contradictions, it is enough to use simple tools of TRIZ: methods of eliminating contradictions, inventive standards. But in some cases, there are contradictions that are not solved quickly. For such tasks, we use more complicated tools, including ARIZ.

Below there are examples of using of various TRIZ tools for solving inventive problems in business systems.

5.1. Analyzing the process of using drinks

The same client we described in section 4.2 had another challenge of scaling their solution. To collect consumption data from their coffee machines they needed to install an additional module in to it. This module detected the type of the drink, which was loaded into the machine and consumed. The client already has many machines around the world and these machines had different design. Retrofitting of all these machines represented a great challenge for the client.

To address this challenge, we considered even more complicated problem, which would give us an ideal solution – how can we identify drink without changing the machine design at all?

To solve this problem, we reviewed the lifecycle of a drink pack in terms of identification of consumption event (see Fig. 8). Our client was focused on this event as the moment of loading the pack into the machine. Therefore, they thought that they needed to do something with the machine to make it able to detect the loaded pack. However, if we look at the pack lifecycle, we would see that the consumer makes decision about which drink to consume when he or she picks it from the merchandiser – a container, that stores drinks near the machine. If we change the merchandizer design in a way that the consumers should “tell” the merchandizer which drink they want, then we would not need to detect anything and would automatically get the information about consumed drink. The advantage of this solution is that modified merchandizer would fit any model of already installed.

Another potential solution is to work with consumed packs when they are removed from the machine and deposited.

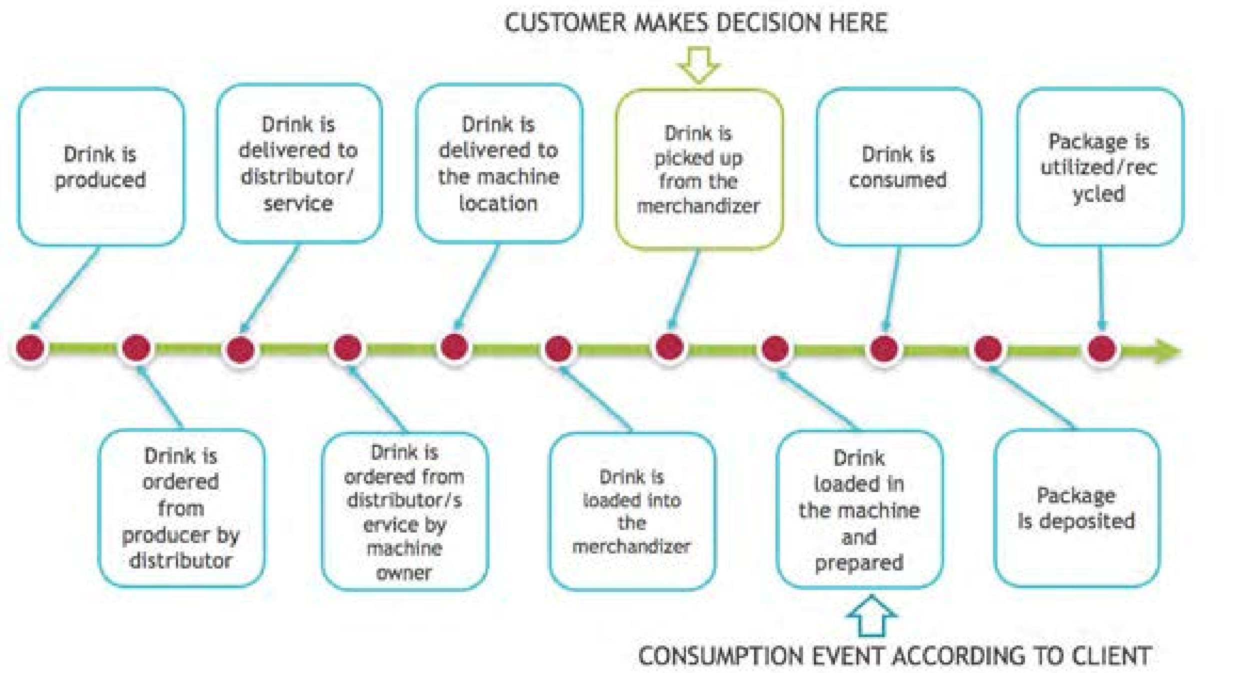


Fig. 8. Life cycle of the drink

5.2. Identifying and solving the contradictions in business process of evaluation the credit rating.

In this case study, we used the following TRIZ methods:

- Root-Conflict Analysis Plus (RCA+)
- Inventive problem solving by ARIZ

The source problem was defined as follows:

Sales department of logistical company working with providing cargo shipping service attracts new customers. Given the fact that shipping services are provided with deferred payment, customer engagement procedure involves a preliminary assessment of the creditworthiness of the client and makes approval of client credibility by Credit Council. Conversion ratio of sales leads to real orders is only 30%, which means that 70% of Credit Councils effort is a waste of time.

What to do in such situation?

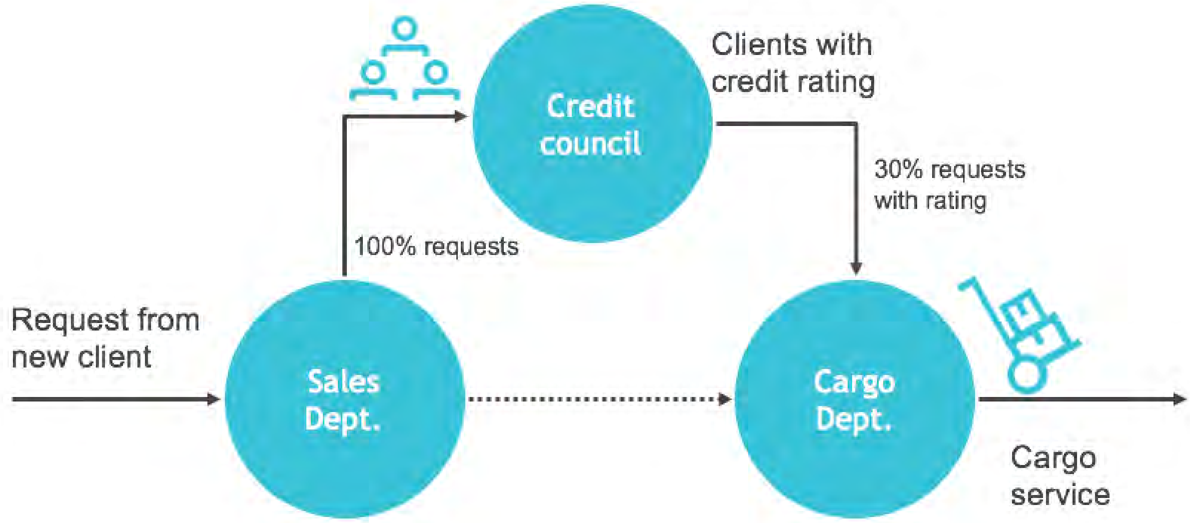


Fig. 9. Credit rating business process

Next figure presents result of RCA+ Analysis of the initial problem and contradiction in requirements.

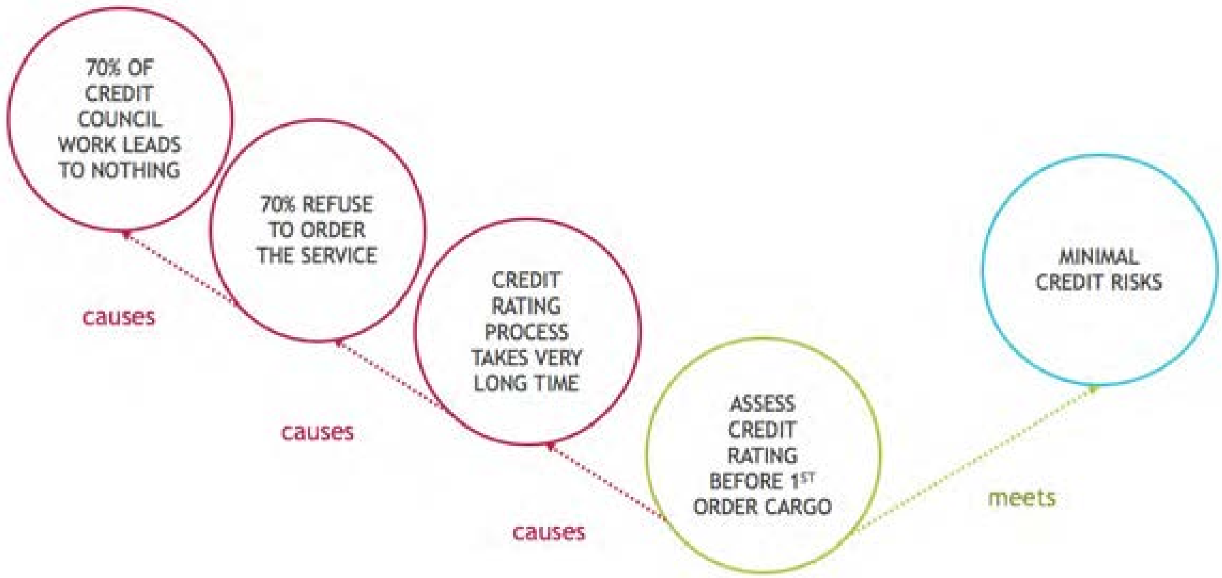


Fig. 10. RCA+ diagram for credit rating problem analysis

Contradiction in requirements. If we save the existing solution as “Assess Credit Rating before 1st order for Cargo” then (+) credit risks are decreased but (-) clients refuse to make the order for Cargo Service. From the other hand if we change existing solution to “Forward request of new customer to cargo dept.” then (+) Clients confirm buying Cargo Service but (-) Credit Risk are increased.

Contradiction in property was defined for Credit Rating process time: this time has to be long in order to decrease Credit Risks, and this time has to be minimal (= 0) in order to Clients confirms buying Cargo Service.

Operational time analysis. Credit rating process duration must be long and minimal in the same time. Operational zone analysis. Credit rating process duration must be long in Credit Council and minimal In Sales Dept.

Ideal final result: Duration of the credit rating process itself changes from 0 in Sales Dept. to the required time in Credit Council.

Solution idea. After receiving request from new client, the sales person makes shortened creditworthiness evaluation procedure and sets initial credit rating sufficient for 1-2 orders. After the start of the 1st Cargo sales person sends a request to the Credit Council to execute full credit rating assessment procedure.

5.3. Solving the problem about dialogue with the visitor (by ARIZ)

The last example which we plan to stop-by is about solving one of the contradictions detected for *car information aggregator* (see Fig. 5 in section 4.1) using ARIZ tool.

Source contradiction: when visitor searches for the car, dialog with the visitor allows to get info about his needs and wishes and find most appropriate cars for him, but visitor must spend a lot of time answering the questions.

Solution idea: After Resources analysis and going with this contradiction through ARIZ the Solution called "Virtual Assistant" has been found. *Car information aggregator* portal uses almost all famous social networks like FB, Twitter, Google Services and others. From the social network profile with a help of data analytics we can form virtual representation of the end-user lifestyle. The last but not the least is that visiting set of web portals and sites Users fill a lot of registration forms answering similar questions.

Solution of the idea. Let the user have own virtual avatar which knows about life style (wishes, needs, fears, etc.) and information about the owner. With this solution *car information aggregator* portal knows almost instantly what car models to offer to the end-user:

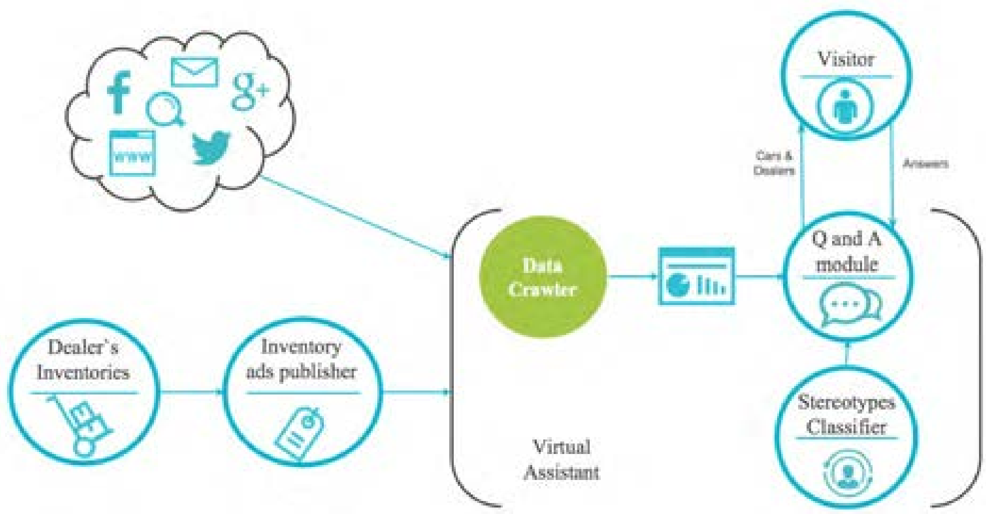


Fig. 11. "Virtual Assistant" Architecture

Speaking on the completely engineering language assistant becomes ChatBot on the user side (User associate) which communicates to the different online services ("Counteraction" TRIZ Principle).

Conclusions

Classical TRIZ oriented on contradiction analysis in engineering systems, finding and solving invention problems in these systems. At EPAM we are constantly facing Client requests which relates not only to engineering system but also to business system of the Client and they expect solutions that make significant impact on the business.

Usage of existing Service Design and Business Analysis tools allows us to analyze the Client's business system and discover existing problems, including inventive problems containing contradictions.

To solve inventive problems in the business system, we use TRIZ tools, such as: functional and lifecycle analysis, techniques for eliminating contradictions, inventive standards and ARIZ. Application of these tools allows to obtain solutions that have significant positive impact on the Clients' business systems and often creates essential competitive advantage.

Acknowledgements

We are enormously grateful to all the members of the EPAM TRIZ team as full co-authors of ideas and solutions presented in this paper.

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APPLICATION OF TRIZ IN ULTRASONIC BRAZING QUALITY

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Abstract

Ultrasonic brazing technology is adopted during the production in order to avoid brazing leakage. We are committed to finding a solution to prevent leakage to minimize cost. In this paper, innovation principles of TRIZ have been adopted, such as the principle of advance, pressure, etc. Brazening leakage and processing method have been studied, and thus optimizing craft tubes brazing solution and control solution were found. It is concluded that TRIZ innovation principles have been efficiently interpreted to cure the leakage of ultrasonic brazing process, provided high quality brazing solution and parameters. In daily production process, the product quality has been improved to achieve zero leakage.

Keywords: ultrasonic braze, fire brazing, craft tube braze

1. Preface

Sometimes room-air-conditioning products are made with craft tube for refrigerant perfusion. After filling refrigerant, craft tube must be airproofed by braze which quality is very much relying on the operator's skillfulness. According to our business statistical data, operators worked on airproof brazing between 1 to 3 years can better control leak rate than those who worked less than 1 year or longer than 3 years.

New refrigerants such as R290, R32 have been tested in recent years for environment protection purpose. Because new refrigerants are combustible, we have adopted ultrasonic brazing technology which is flame-free on airproofing craft tube. However, leak rate from ultrasonic brazing technology was much higher than traditional brazing technology at early period. The exact causes of leak were found with the help of TRIZ's methods. Solutions were found with TRIZ invention principles. With ultrasonic brazing technology, product leak rate is lower than traditional brazing technology, thus the skillfulness of workers is now less important to production as ever.

2. TRIZ application on improvement of the brazing quality

2.1. Solution about braze fault that caused by craft tube's oxidation

According to the corporate's quality requirement, a destructive test must be conducted to prove the quality of brazing procedures. After brazing of samples, the destructive test of the specimens is performed. Mass production would be suspended should the destructive test fail, investigation must be conducted to track the root of problem. In the prenatal destructive experiment, due to the fire brazing, the brazing point between the craft tube and fork type filter was very much oxidized which resulted in ultrasonic brazing pressure tolerance failure. The pressure tolerance was only 50% compared to traditional technology. Contradictorily, the fork type filter must be welded with brazing.

The project team built up a cause effect chain analysis (CECA) as follows, see Fig. 1.:

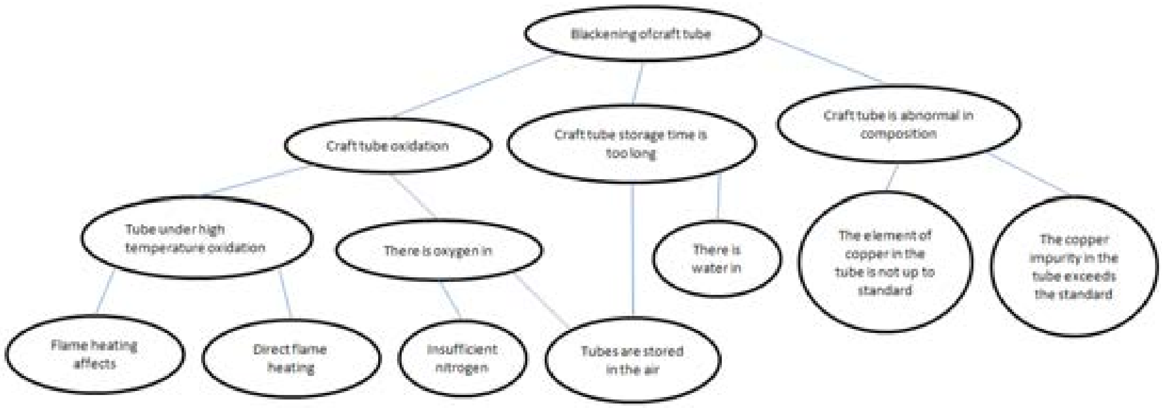

Fig. 1. CECA of craft tube's oxidation

Since the craft tube has no direct contact with the flame, "flame heating relations" was targeted to seek the cause. The problem was converted into technical contradictions, which are described as follows:

Craft tube made by copper and fork type filter were brazed together by flame welding. However, the craft tube ultrasonic brazing point would be heated and darkened, resulting in the braze destructive test failure.

To translate the problem into technical contradiction, see Table 1:

Table 1

Technical contradiction about flame welding and ultrasonic brazing destructive test failure

Technical contradiction about flame welding and ultrasonic brazing destructive test failure	
if	A: the flame is near the tube,
then	B: the craft tube and fork type filter can be welded together as a component.
but	C : the craft tube ultrasonic brazing point was heated and darkened resulting in braze destructive test failure.

Improving and deteriorating parameters were changed into current Altshuller's Matrix engineering parameters. See Table 2:

Table 2

Altshuller's Matrix engineering parameters

	Detailed parameters	General engineering parameters.
Improving parameters	Braze together by flame welding.	12. Shape
Deteriorating parameters	Darken due to oxidation	23. Materials loss

Selected cells in Contradiction Matrix are described as follows, see Table 3:

Table 3

Contradiction matrix

Deteriorated parameters / Improved parameters		Damage of Materials
		23
Shape	12	35,29,3,5

Taking into account invention principles of 35,29,3,5 "3 - local quality" was found to be adopted for problem solving. Local quality is understood as:

1) Changing homogeneous material structure, by external environment forces to heterogeneous material structure;

2) Enabling different parts to be functioning independently

3) Enabling each part to operate in its optimal mode

According to above point 2, when the craft tube and fork type filter were brazed with flame, the welding point would be heated and darkened, the other end of the craft tube could be treated by ultrasonic brazing. Therefore, the project team invented a new device for brazing process, see Fig. 2.:

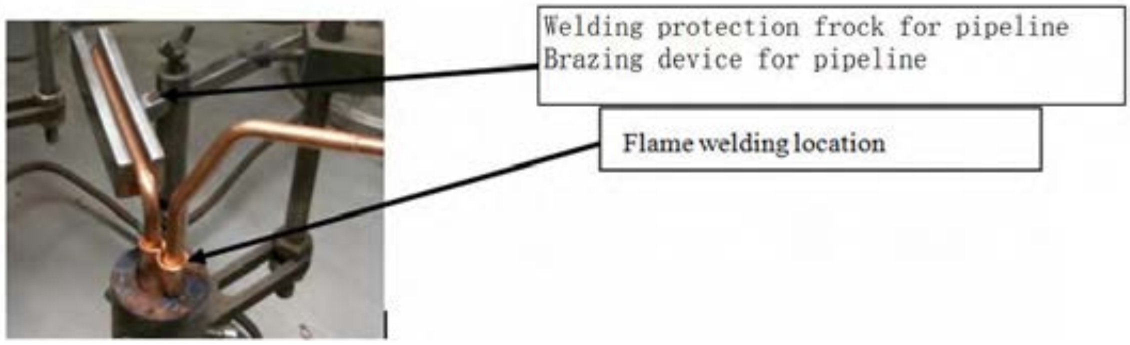

Fig. 2.

With nitrogen protection, the oxidation caused by brazing with flame has been dramatically dropped. Introducing the new device for brazing, no darken points were found inner of the sample craft tube (see Fig. 3 while sample craft tube remains darkened without introducing the new device (see Fig. 4)

Fig. 3. Sample without new device introduced

Fig. 4. Sample after introducing new device

"Destructive test" results with/without introducing new device are shown in Table 4:

Table 4

Contradiction matrix

"Water pressure test" results		
No.	Group A without new device	Group B with new device
1	NG	OK
2	NG	OK
3	NG	OK
4	NG	OK
5	NG	OK
6	NG	OK
7	NG	OK

8	NG	OK

By applying the '3-local quality' invention principle, the problem of destructive test failure was effectively solved.

2.2. Solution about reset and re-seal

When ultrasonic brazing technology was adopted in early period, leak rate was high and leak alarm triggered frequently. Reset and re-seal after braze fault is critical for leaking with ultrasonic brazing technology.

Equipment must be reset once braze fault is observed and alarm was triggered. The air leaked braze products must be resealed. However, during production, resealing of air leak tubes was frequently forgotten after resetting of equipment. The air leaked tubes therefore return to the production process to the next processing step. In order to solve the problem, it was converted into technical contradictions and solutions were searched.

When the technical problem was converted, the problem is described as: if the fault alarm keeps on shining as braze leaking. The production line pauses unless the Reset signal got switched off, hence reseal won't be forgotten.

Converted problem into technical contradiction is presented in Table 5:

Table 5

Technical contradiction about braze fault

Technical contradiction about braze fault	
if	A: Reset button was not pressed
then	B : Fault alarm will keep on shining as braze leaking. The production line pauses.
but	C : Resealing won't be forgotten.

Improving and deteriorating parameters were changed into current Altshuller's Matrix Altshuller engineering parameters. See Table 6:

Table 6

Technical contradiction about braze fault

	Detailed parameters	General engineering parameters
Improved parameters	The production line pauses and the efficiency is low.	39. Productivity

Deteriorative parameters	Resealing is not forgotten, hence to ensure product quality	32. Manufacturability

Invention principles are confirmed by locating in Altshuller's contradiction matrix.

35: Transformation of physical or chemical data

28: Mechanics substitution

2: Extraction

24: Assist with mediator

After discussion, '35 Transformation of physical and chemical data change' invention principle does not solve the problem; "28 mechanics substitution" is helping, however investment of additional equipment is needed, and it takes too long time to get problem fixed Under 2 Extraction, the reset button can be controlled by operators from other departments combining "24 Assist with mediator". Thus "2 Extraction" and "24 Assist with mediator" were chosen to solve the problem.

The reset process is done by QC (Quality Control) who is working with production line. QC will ensure the resealing of the air leak product and confirm the reset of equipment. To ensure the reset process being done by OQ rather than anyone else, permission will be applied to the Reset device. Since this process applied, resealing has been 100% implemented to products in need.

Yet there are 30% faults occurred during production and thus resealing is needed. Not to mention, QC's were in frequent needs to control the reset and supervising resealing which increases its workload heavily. A solution was then proposed, the passing rate of one-off brazing must be 100%, supervising resealing is nevertheless a must.

2.3. Solution about cutting-edge on craft tube

To reach 100% passing rate of one-off brazing, craft tube must be straight cut. To process craft cube brazing, operators had to move with the same speed where the production line conducted. Some of the air leaking tubes were found with inclined cutting edge (see Fig. 5), while a passed brazing is with rectangle cutting edge. The increasing production line speed requested operators to move faster and thus more inclined cutting edges were made which resulted in higher air leaking rate. Physical contradiction theory was then adopted during problem analysis.

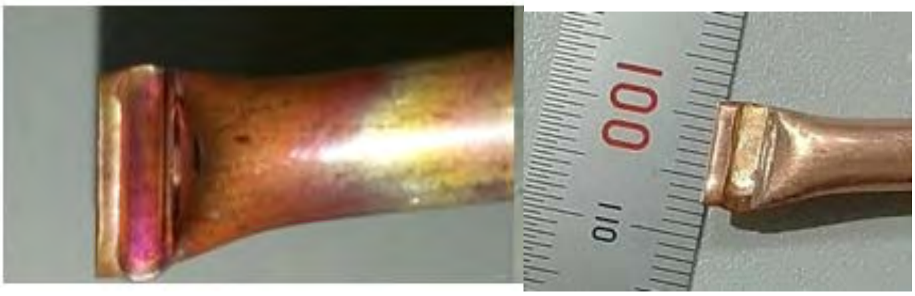

Fig. 5. Parallel Unparalleled

Craft tube should be close to brazing blade to get cutting accurate. Contradictorily, the craft tube shouldn't be close to brazing blade so as sealing speed would be increased.

The "Extraction" physical contradiction resolving principle is based on connection-separation. From theories of invention principles, 'Extraction" based on connection 3/17/19/31/32/40', principle "17/ Multi Dimensions" was applied to this case.

Metal detecting sensor is installed at both sides of the blade, in order to ensure craft tube is in touch with both sides of the blade. Equipment will then be switched on by operator. Neither side of the metal sensor is got touched nor none of the sides are got touched, the equipment won't be switched on. (See Fig.6.)

Fig. 6. Equipment condition when tube is not probably touched with blade (left picture) and when tube is well in touch with metal detecting sensor (right picture)

It must be noted that during the production, equipment might be moved by operators for adjusting process. Once the position of equipment exceeds the reach of brazing blade, it is very likely the craft tube would get inclined cut. According to the invention principle of Multi dimensions, movement of equipment should be restricted within certain degree, to ensure that both sides of the blade would be in touch with the craft tube. In the end it may eliminate the chances of inclined cutting on craft tubes and ensure brazing quality.

After adopting the above solutions, inspection of products from 3 different shifts found one-off braze pass rate is 100%.

3. Conclusions

By adopting the cause effect chain analysis and the TRIZ analysis method for resolving contradictions, we have found solutions for ultrasonic production problems: our engineers came up with fast solutions with minimum cost. Thus, it provides a way to analyze and solve problems from production line. It improves the product quality significantly, reduces the production cost and enhances product competitiveness positively. The benefits are as follows:

In search of process innovation and on site problem solving innovation, TRIZ principles have been applied, and the findings are: solution based on causal effort chain analysis, solution of technical contradiction of mechanical products, and solution of physical contradiction. Based on the site requirements, a TRIZ based on-site problem solving scheme and solution framework is proposed, which proves TRIZ is greatly useful for corporate process innovation.

Copper tube being treated by ultrasonic brazing was with oxidation due the heat caused by, solution has been found under guideline of TRIZ. Solutions of ensuring resealing has significantly improved production efficiency. According to Corporate statistics, the number of ultrasonic brazing failures dropped to zero. Product quality has been improved, production is now less relying on operator's skillfulness, as well as the flame operation is avoided therefore.

Acknowledgements

This paper is a testament to the family and friends who selflessly gave me the time, love, and moral support I asked for. First of all, I would like to thank my colleague Yu Na for introducing me to TRIZ, teaching me to master TRIZ, and providing assistance in the TRIZ theoretical guidance of this paper.

On the occasion of this paper, I would like to express my heartfelt thanks to my superiors, Minister Zhong Mingsheng and Minister Wang Wenbin. There is a lot of resistance pressure during the TRIZ method is applied to the process quality problems of the specific production process. It was unknown whether the method could solve the urgent problems of production. The Managers withstood the pressure at the critical moment so the problem solving team could easily follow TRIZ steps, completed problem analysis, found causes and solved problems.

Thanks to GREE ELECTRIC APPLIANCES, Inc of Zhuhai which state approved laboratories and technical resources were greatly giving support during the process. In the course of writing the paper, it has also received strong support from other members of the department for providing guidance of testing program.

Thanks to my family, thank you very much my old friend, MS. Angela Liang, they gave me encouragement and support when I was in trouble.

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APPLICATION OF TRIZ TO RESEARCH COMMUNICATION SKILL DEVELOPMENT

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Abstract

The trend towards interdisciplinary research in higher education has exposed a need for research communication strategies that support better communication across disciplinary boundaries. This paper introduces a practical framework developed for enhancing the research communication skills of engineering students. The framework uses TRIZ tools such as the 40 inventive principles, su-field model analysis and 76 standard solutions. Initial use of the framework with a number of students has shown it to be effective in making research easy to understand across disciplines.

Keywords: Research Communication, Interdisciplinary Research, Engineering, TRIZ

1. Introduction

In its long history, university education has focused on transferring specialized knowledge accompanied by research experience under professional supervision of experts in the field of study. However, recent advances in information technology giving access to most information needed decrease the value of memorized information. University faculty members may have played a central role as specialized information experts in the fields, but now a large part of this function can be played by the internet.

Moreover, with recent intense changes in the business environment, many students find that a large part of field specific knowledge including research work completed in university education, may not be required after their graduation. While research activities in a closed laboratory environment tends to improve field specific knowledge in the supervisor's specialty and provide experience in the problem-solving process, it offers minimal opportunity for not only fostering other useful skills, but also limits the search for alternative solutions through communication with researchers in different fields.

One visible trend in higher education and research is the emphasis being placed on interdisciplinary research with researchers being encouraged to communicate across disciplinary boundaries. Many universities have started interdisciplinary research centres and adopted approaches such as joint degree programs, double supervision systems and interdisciplinary workshops for exchange of research achievements between researchers from different fields with the aim of promoting greater collaboration. Rather than focusing on highly specialized knowledge in specific subject, there is a growing emphasis on fostering of skills that contribute to development of solutions for the many pressing issues that cut across different fields. As such, the authors see a growing need for researchers in engineering to develop effective research communication skills that can help advance collaborative research efforts.

2. Research Communication Skills and TRIZ

To communicate research effectively, a researcher should be able to clearly (1) define the research problem, (2) share the research outlines across different fields, (3) share the core problems faced in the research work across different fields, (4) propose ideas and solutions that consider input from different fields, and, (5) apply knowledge gained in one field to another field. This skill should be emphasized as one of the essential skills to be obtained through the university research experience.

The authors have been engaged in activities supporting the Academic English writing skill development of engineering students. Through these activities, the authors have found that in addition to the language skills, there is a strong need for research communication skills that can support collaborative work across different fields. The authors use the term "Research Communication Skills" to refer to the skills needed to effectively communicate research ideas between different fields.

The authors have previously used the term "Research Communication Skills" [1] which focused on supporting students' academic English writing which is an essential part of laboratory work. Especially in non-English speaking countries like Japan, the article writing process often requires checking from external support divisions or translation companies whose staff is usually not specialized in the field that the client needs support. They struggle with how to share and properly reflect the research contents in the article. Therefore, the authors see academic English writing as a good example of an activity that can greatly benefit from better research communication.

In the previous research paper, we use TRIZ for clarifying research objectives and the conclusion [1]. In that paper, the TRIZ concepts of solving contradiction based on the 39 parameters were used in workshops to organize the multitude of information that students need to sort during their research activities. Function analysis was also used to clarify the key technical point of their research. These workshops provided students with a new method of rethinking research objectives and refining communication of their research findings. The authors received positive responses from participants of these preliminary workshops.

This paper further expands on our initial "Research Communication Skills" development method by using the following TRIZ tools: (1) if then but statement", (2) 40 inventive principles, (3) function analysis that may further be connected to the application of su-field model analysis and the 76 standard solutions.

TRIZ offers clear problem definition and problem-solving strategies that are common across all engineering fields. While the tools featured in TRIZ are normally used in problem solving, they clearly can be applied to developing a methodology for supporting development of better research communication in interdisciplinary settings. The authors see a big potential for TRIZ in the organization of the chaotic information generated through the trial and error processes inherent in many research activities so as to make research more understandable across fields.

3. Development of a Research Communication Framework

This section introduces Research Communication Framework for supporting interdisciplinary research communication. The framework has been developed through discussion with students and faculty members who have authored or were in the process of writing academic papers.

Fig.1 shows the situation in a conventional research environment which is closed and boundaries exits between study fields hampering cross communication. The figure depicts researchers on their complicated research quest through trial and error going from a research problem to its solution. From experience in past workshops, this complicated maze like process often lead researchers to loss clarity on the research purpose. In addition, the wall between different engineering fields hinders the interaction and sharing of potential solutions across the fields.

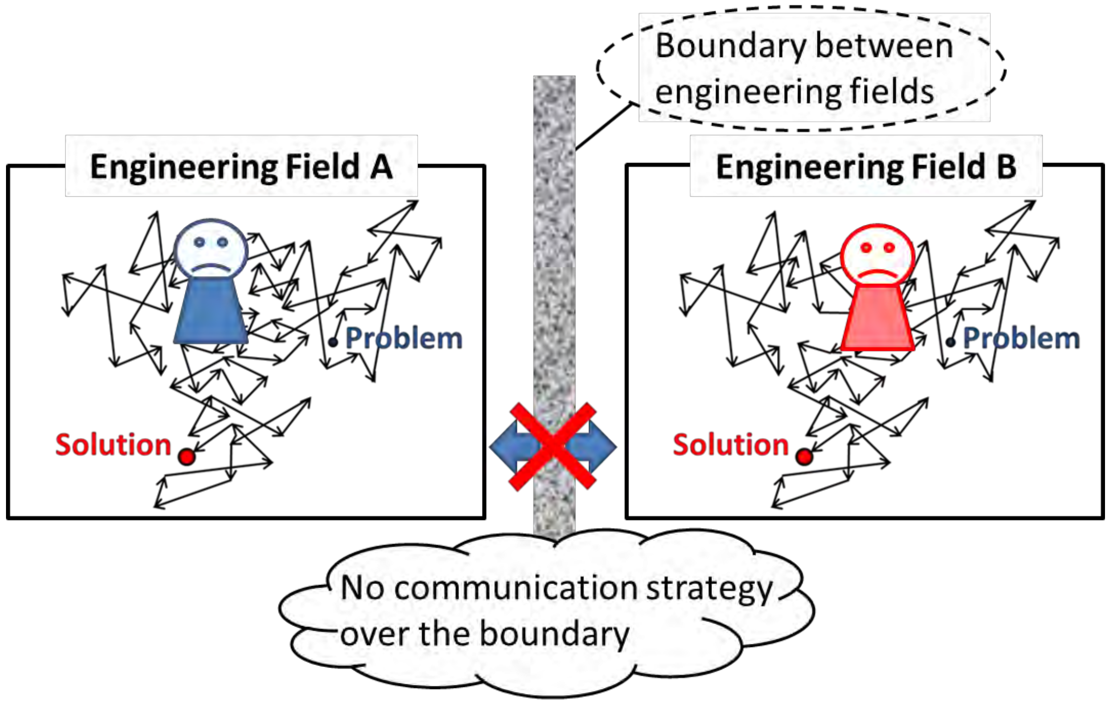

Fig. 1. Problem in research communication across field boundaries

Fig.2 illustrates the introduction of a research communication framework to not only create a channel for communication across disciplines, but also to guide researchers in research activities, by ensuring that the extraction of the research essence which is minimum information for clear and fruitful interdisciplinary communication. The authors have narrowed the research essence into the following three components: (1) Research Outline Description, (2) New Engineering System Description and (3) Core Research Problem Description. With information gained from the three components, a researcher can obtain the essential information required for communicating their research problem with researchers in other different field leading to a higher possibility of collaboration and innovation.

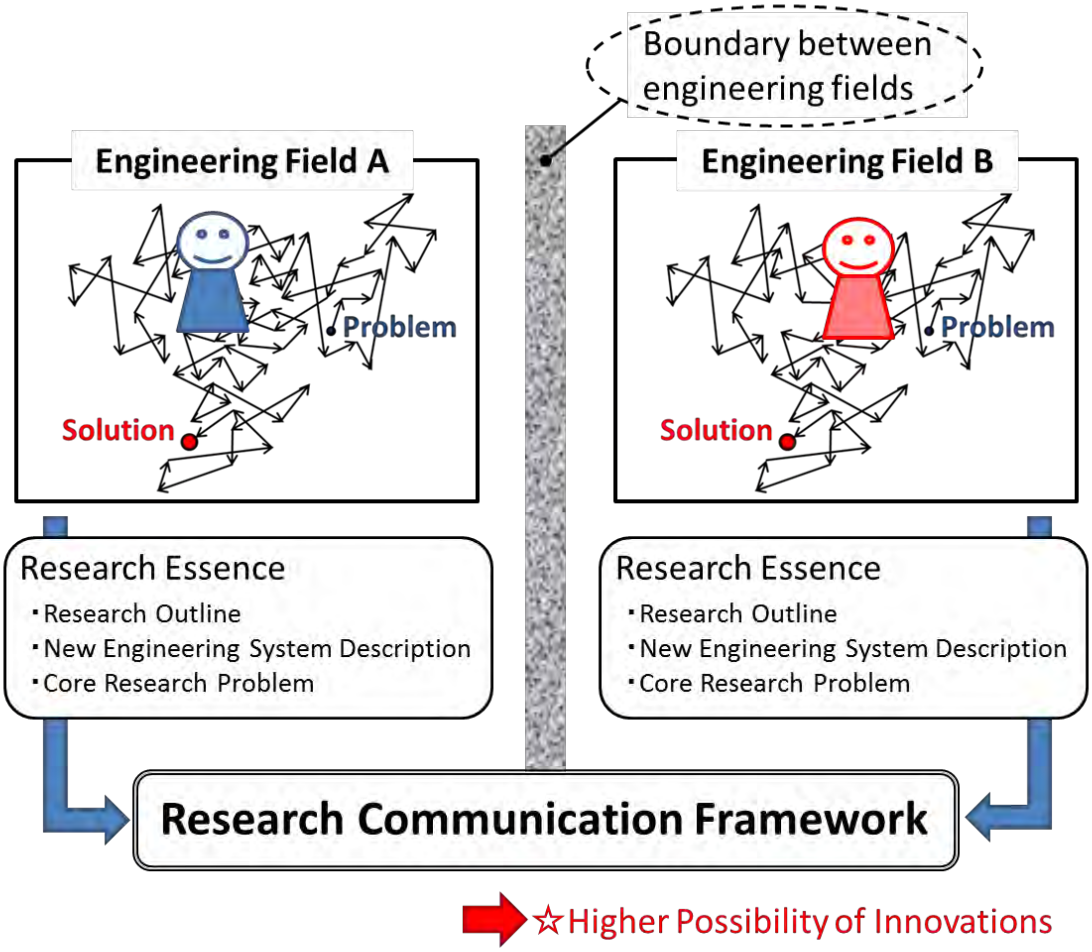

Fig. 2. Strategic research communication with Research Communication Framework

The example we will be using in this section to demonstrate research communication utilizing the components mentioned above ((1) Research Outline Description, (2) New Engineering System Description and (3) Core Research Problem Description) is of a research focusing on the development of an automated vehicle stop system for cardiac emergencies case example.

3.1. Research outline Description

Research Outline Description is the simplified form of research motivation so that research content can be shared across different engineering fields. Researchers sometimes fail to clearly explain their research when they give too many details to others especially those in different fields. Fig. 3 shows the achievement components in Research Outline Description. The origin of Research Outline Description is the “If then but statement” and “Ideal Final Result” in TRIZ [2], but it has been modified for use by students without TRIZ knowledge. The research goal is defined by four components: “Conventional Engineering System”, “Positive Effect”, “Negative Effect” and “New Engineering System”. The Conventional Engineering System has been designed to generate a Positive Effect but it inevitably also generates Negative Effect. A New Engineering System is then required to eliminate the Negative Effect. Developing this New Engineering System is the focus of the researcher.

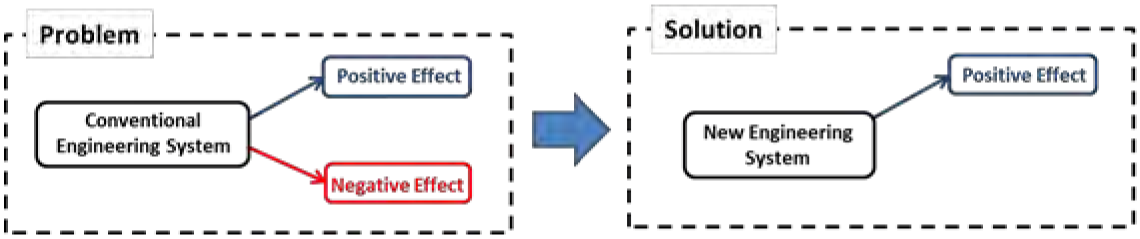

Fig. 3. Illustration of research outline components

This figure is completed by asking the following four questions;

1) What is "Conventional Engineering System" in your research?

2) What is "New Engineering System" in your research?

3) What is the "Positive Effect" generated from "Engineering System" of your interest?

4) What is "Negative Effect" in your research?

These questions can be stressed as important clues for interdisciplinary research communications.

As described by "If then but statement", a problem in any engineering field is defined as a conflict of positive effect and negative effect. This is common across all engineering fields. The Research Outline Description can be used as a starting point understanding and sharing research problem in unfamiliar fields. The answers for the four components in the Research Outline Description must not be technical terminology but general terminology.

Study Example:

Fig. 4 shows Research Outline Description of our case study example,. "Conventional Engineering System" is "Normal Automobiles". This system aims to obtain the "Positive effect" of "Move persons at fast speed" but also generate "Negative Effect" of "Traffic Accidents". The "New Engineering System" that is to be developed through research is "Automobiles with an automated vehicle stop system for cardiac emergencies". This system will eliminate "Traffic accidents caused by cardiovascular disease (CVD).

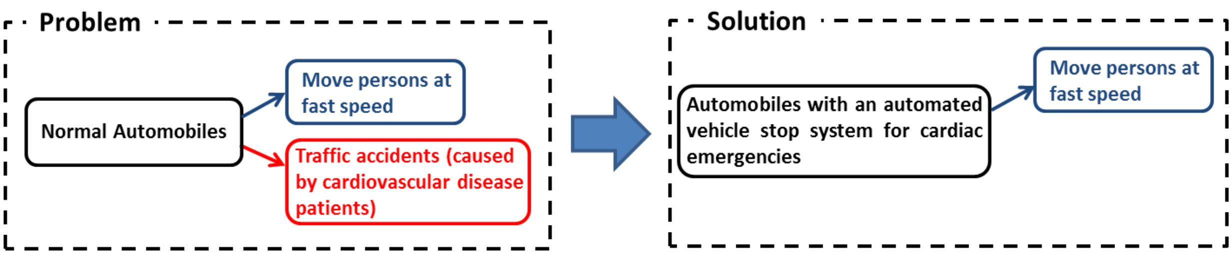

Fig. 4. Study example of Research Outline Description

3.2. New Engineering System Description

After defining the research motivation by using Research Outline Description, the details of the research also need to be communicated. The 40 inventive principles [3], which are shared across all engineering fields, can be utilized in listing descriptions of the difference between the Conventional Engineering System and the New Engineering System. The researchers should be able to clearly share their research contents with respect to 40 inventive principles. This process enables us to envision the goal of the research through clear descriptions of the New Engineering System. Of course, it is possible to arbitrarily explain the details of New Engineering System, but the authors see the 40 inventive principles as the best option for systematically and adequately describing the features of the New Engineering System.

Study Example:

The table below shows some of the features of the New Engineering System (from our example of "Automobiles with an automated vehicle stop system for cardiac emergencies") described using 40 inventive principles. This process exposes the key points in the system under development.

Table1 New Engineering System Description

1, Segmentation	This research segmentalizes drivers into normal drivers and drivers with CVD
2, Taking out	The system developed in this research aims to take out accidents caused by drivers with CVD
3, Local Quality	The system developed in this research focuses on drivers with CVD. The system is activated when driver is under emergency situation caused by CVD.
5, Merging	The situation of drivers with CVD is tried to be detected by merging multiple technologies such as image analysis and bio-sensors.
9, Preliminary Counteraction	The system are programmed to automatically park the automobile in emergency situation of drivers
11, Beforehand Cushioning	The system is cushioning for drivers under the risk of emergency situation caused by CVD
15, Dynamics	The system increases functionality dynamics of automobile adjusting to the drivers with CVD
23, Feedback	The drivers' situation is monitored through image analysis and bio-sensors and feedbacked for the operation in emergency.
26, Copying	The drivers' situation is copied by using bio-sensor and camera.
28, Mechanics Substitution	The automobile is programmed to automatically controlled under the emergency of drivers with CVD

3.3. Core Research Problem Description

The Research Outline Description and the New Engineering System Description process above guides researchers to get an overview of their research with clear information about what is new in their "New Engineering System". But researchers often are actually dealing with a more detailed problem in developing the New Engineering System. The “Core Research Problem Description” offers a clue to the detailed problem that need to be solved to realize the “New Engineering System”. If a researcher fails to extract the “Core Research Problem”, they might not be able to not only communicate their research effectively, but they may also fail to obtain meaningful research output.

Researchers in engineering fields are trying to solve at least one of the following problems which is inspired by function analysis description [4].

(1) Something (Tool) insufficiently acts (Function) on Something (Object).

(2) Something (Tool) harmfully acts (Function) on Something (Object).

(3) Something cannot be measured sufficiently.

The “Core Research Problem Description” can be extracted by asking the researcher to state which of the above 3 their research targets.

For those who choose (1) or (2) as their Core Research Problem, identification of Tool, Function and Object will clearly define their research problem. Those who choose (3) deal with a problem of detection and measurement. It is recommended that they reorganize their research problem into the following sentence: (3)’ Something (Tool) insufficiently acts (Function) on Something (Object: e.g. Sensor) insufficiently. Therefore, the core research problem can also be clearly described by identifying Tool, Function and Object (e.g. Sensor).

Study Example:

Following the communication process introduced above, “Something cannot be measured sufficiently” was identified as the core research problem. This was transformed into, “Something (Tool) insufficiently acts (Function) on Something (Object: e.g. Sensor) insufficiently”. The Core Research Problem was defined as “Attributes of CVD patient insufficiently informs Sensors.”. Further consultation with the student identified the following two problems which are even more concrete, “The posture of CVD patients insufficiently informs camera.” and “The heart beat insufficiently informs Bio-sensor”. Therefore, while the stated goal for the research was “the development of Automobiles with an automated vehicle stop system for cardiac emergencies”, the research problem of focus might be something that is not specific to vehicles, for example, the “development of a better heart beat monitoring Bio-sensor”.

4. Response of Students

The methodology introduced above was applied to activities in an interdisciplinary workshop, which is a part of the second seminar of “JSPS Core-to-Core Program: Establishment of Research Hub for Compact Mobility Model in the ASEAN Region” at Chulalongkorn University, Bangkok, Thailand, on Aug. 2, 2017. The feedback has shown 11 in 13 students, where the number of total participants were 14, had positive feeling on the concept of Research Communication Skill.

5. Concluding Remarks

With the increasing trend towards interdisciplinary research in higher education, better research communication strategies are needed for researchers to productively work together across disciplinary boundaries. In this paper, the authors have adapted TRIZ methodologies to come up with three-step framework for enhancing communication between disciplines. The “Research

Outline Description" and "New Engineering System Description" steps are useful in understanding the goal of the research, while the "Core Research Problem Description" step clarifies the actual problem being dealt with by a researcher. This framework is still in development; the authors plan to further gauge its effectiveness in supporting interdisciplinary communication through practical use in research communication skill development workshops.

Acknowledgements

The authors would like to thank all the students who participated in the interactive discussions for the development of Research Communication Framework and show sincere gratitude to Mr. Tung T. Nguyen who allowed us to introduce his research as the study example. The workshop mentioned in this article was supported by JSPS Core-to-Core Program, B. Asia-Africa Science Platforms.

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APPLYING TRIZ TO IMPROVE LEAN PRODUCT LIFECYCLE MANAGEMENT PROCESSES

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Abstract

In industry, the migration to an Agile and Lean product development culture has become a major movement for companies (e.g. Siemens) to face the constantly increasing speed of innovation. The successful and sustainable implementation of an Agile/Lean approach seems to be mission critical for the future success of companies.

The paper illustrates examples of how TRIZ can enrich the Agile and Lean development approaches by bringing in the TRIZ thinking, mindset and toolbox into specific Lean tools like Hoshin Kanri, A3-reports, PDCA and Set-based Design. We analyzed 12 projects which cover different types of focus topics e.g. process improvement, innovation or portfolio development. The research points out what aspect of the TRIZ methods introduce additional knowledge in the Lean Product Life Cycle management. Most of the examples are already verified in real projects in industry and have proven to be helpful.

Keywords: Theory of inventive problem solving (TRIZ), Agile, Lean, A3-report, Hoshin Kanri, Set-based Design

1. Introduction

Based on evolving technologies and shorter product life cycles, the speed of innovation is constantly increasing. In industry, the migration to an Agile and Lean product development culture has become a major movement for companies (e.g. Siemens). The successful and sustainable implementation is mission critical for the future success.

Lean and Agile development provides a lot of values, principles and methods for successfully directing the organization on customer value and a lot of guidance how this should be implemented with cross-functional, autonomous teams. Related to waste reduction in development processes, innovation targets (areas) and the goals for a sustainable development of the portfolio, Lean provides no methodology how existing knowledge about technical evolution patterns could be effectively integrated into the process. This is the area where TRIZ has the potential to bring in a significant value add.

The paper illustrates examples of how TRIZ can enrich the Lean development approaches by bringing in the TRIZ thinking, mindset and toolbox into specific Lean tools like Hoshin Kanri, A3-reports, PDCA and Set-based Design. We analyzed 12 internal projects which cover different kinds of focus topics e.g. process improvement, innovation and portfolio development. The research points out what aspect of the TRIZ methods introduce additional knowledge in the Lean Product Life Cycle management. Most of the examples are already verified in literature or real projects in industry and have proven to be helpful. The main question of this research is how to combine the Lean and TRIZ approach in a structured way in order to significantly improve the Lean approach in the area of product development. Moreover, the paper illustrates the correlation between Lean and Agile. We use the following approach to answer the questions:

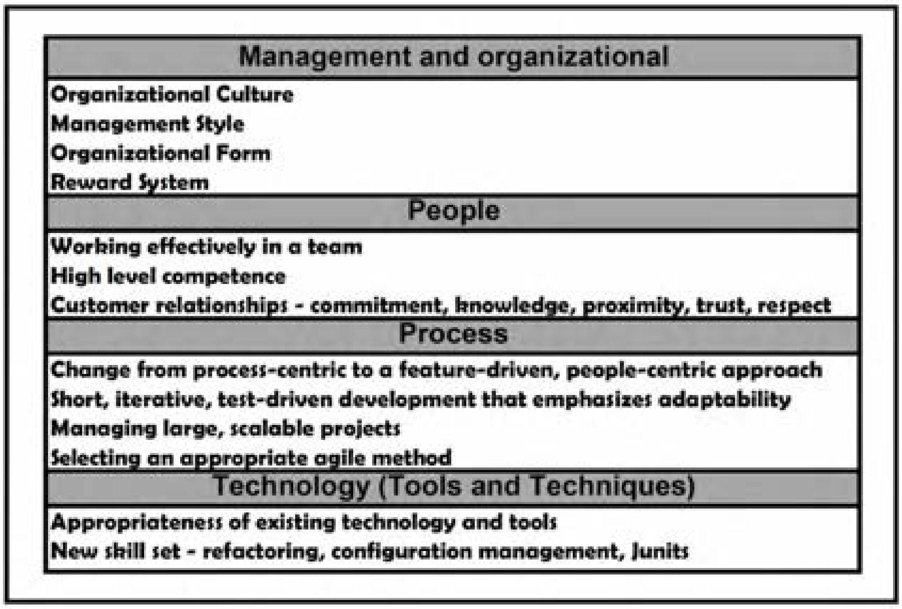
1. Visualize the key methods/ideas/working models of Lean in product development
2. Categorize different kind of projects in the field of product development
3. Discuss the experiences applying TRIZ methods in this different project types
4. Attach TRIZ methods into the Lean working models

2. Literature Review

2.1. Agile and Lean product development culture

Due to new technologies, requirements and user-demands, development methodologies (especially for software) are constantly evolving [1]. The dynamic market conditions motivates organizations to continuously adapt and reinvent their structures, strategies, and policies to deal with it [2]. These organizations need information management systems that continuously react and develop to meet their changing demands [2]. However, the traditional development methodologies (e.g. roadmaps, requirement specifications) do not have the flexibility to dynamically adjust the development process [2].

Especially large organizations have followed the goal of continuously optimize, improve and create repeatable processes [3, 4]. The stability they created represents one of the biggest problems in adopting an Agile development approach. The differences between traditional and Agile methodologies suggest that organizations must rethink their goals and reconfigure their organizational, human, managerial, process and technology components to successfully adopt Agile methodologies [2] and create a dynamic organization.



Management and organizational
Organizational Culture Management Style Organizational Form Reward System
People
Working effectively in a team High level competence Customer relationships - commitment, knowledge, proximity, trust, respect
Process
Change from process-centric to a feature-driven, people-centric approach Short, iterative, test-driven development that emphasizes adaptability Managing large, scalable projects Selecting an appropriate agile method
Technology (Tools and Techniques)
Appropriateness of existing technology and tools New skill set - refactoring, configuration management, Junits

Fig. 1. Main topics in adopting Agile methodologies [1]

In 2001, seventeen independent-minded software practitioners signed the Manifesto for Agile Software Development with the current values [4, 5]:

- individuals and interactions over processes and tools,
- working software over comprehensive documentation,
- customer collaboration over contract negotiation,
- responding to change over following a plan.

Supporting processes, tools, documentation and contracts are essential elements and usually integrated into workflows and internal processes [3]. However, there is a strong need for interactions between individuals besides the regular processes and workflows to increase speed [4, 5]. It facilitates sharing information and changing the process quickly when it is needed.

Traditional development approaches supposed to anticipate the complete set of relevant requirements early and reduce cost by avoiding changes [5]. Traditional process management (by continuous measurement, error identification, failure analysis and process refinements) lead to drive dissimilarities out of business. It assumes that variations are the result of mistakes and waste that should be eliminated. Nowadays, while process problems might cause some errors, environmental changes cause mission critical problems. Driving down the cost of responding to changes is the only feasible strategy, because we are not able to eliminate them [5]. The new strategy of companies is to reduce its related cost, rather than eliminate the rework. However, expectations have grown over the years and the market expects innovative, high-quality software that meets its needs [5].

The concept of Lean and Kaizen has a strong impact on the way Agile is being used [3] and implemented in companies, filling the gap related to continuous improvement processes. "Leagile" software development describes the application of Lean approaches in Agile software development. [6] Preliminary, the evolution of Agile is focused on evolving the product toward a better fit with requirements [2]. Within the Agile approach both, the product and the requirements are refined through experience. Kaizen, is a continuous improvement method used in

Lean and focuses on the development process itself. When Kaizen is used in an Agile project, the participants suggest ways to improve the fit between the product and the requirements and furthermore offer ways to improve the process in use [2].

Lean in the product life cycle management and Agile environment provides a lot of methods for goal setting and implementation of improvement measures with Hoshin Kanri including the PDCA (Plan, Do, Check, Act) improvement cycle [8], Problem analysis (e.g. A3-report [8], Root Cause Analysis with Ishikawa-Diagram [8], 5-Whys [8], Value Stream Mapping [9] for current state / target state modeling) and generating solution alternatives with Set-based-Design and a stepwise approach to derive a final solution. No attempt will be made to explain them in detail in this article. However, we want to highlight Hoshin Kanri and the A3-report for the further work. Figure 2 shows the goal setting of Hoshin Kanri which defines target states for different time scales. The implementation of measures is done with small PDCA improvement cycles.

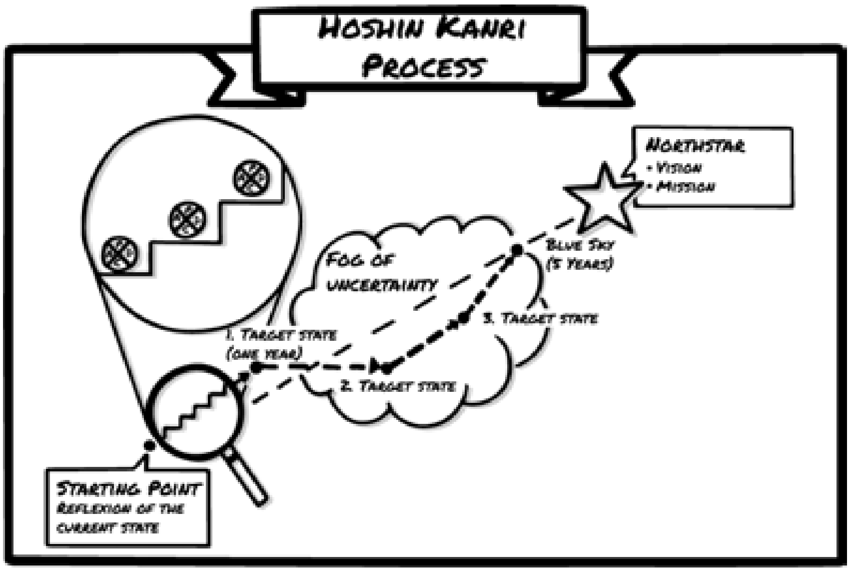


Fig. 2. Hoshin Kanri [8]

Within Siemens, one PDCA cycle is typically planned with an A3-report (see figure 3), which contains the main content background, current state analysis, root cause analysis, target state definition, definition of measures to reach the target state and verification of the effectiveness of the measures.

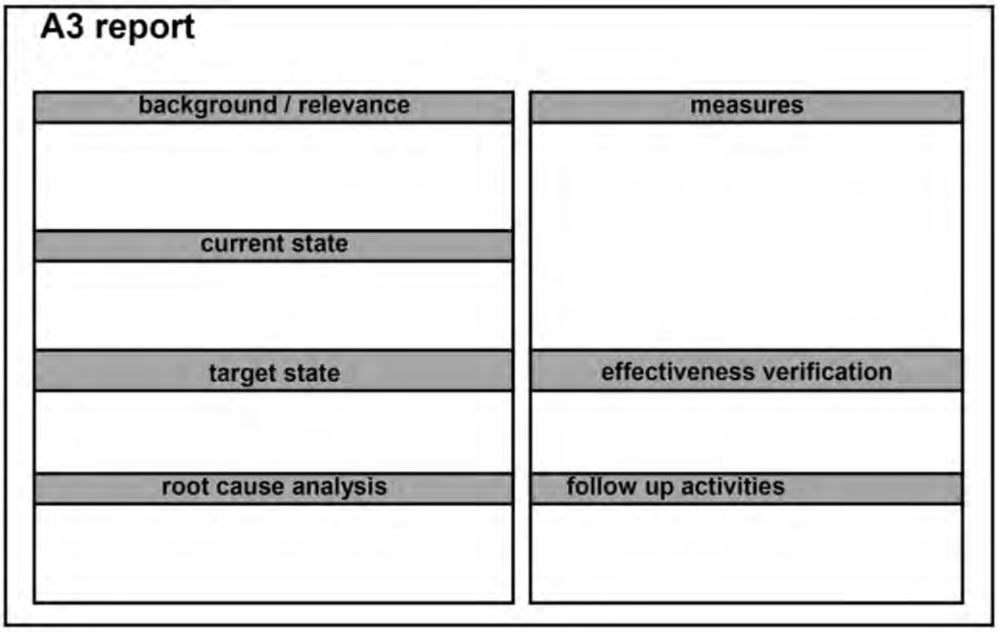


Fig. 3. A3-report [8]

2.2. TRIZ for product development

The Theory of Inventive Problem Solving (TRIZ, TIPS) is known as one of the most powerful inventive methodologies derived from the analysis of the world patent collection [11]. It provides methods for problem-solving and innovating systems in a methodological way.

TRIZ includes different methods to model the problem, abstract the problem, derive an abstract and a specific solution using specific problem solution patterns including empirical knowledge about typical technical evolutions (figure 4). No attempt will be made to explain them in detail in this article. Frequently used TRIZ tools & techniques are described in various articles and papers. The authors recommend the following collections from Ilevbare et al. and Münzberg et al. [10, 11] to get an overview.

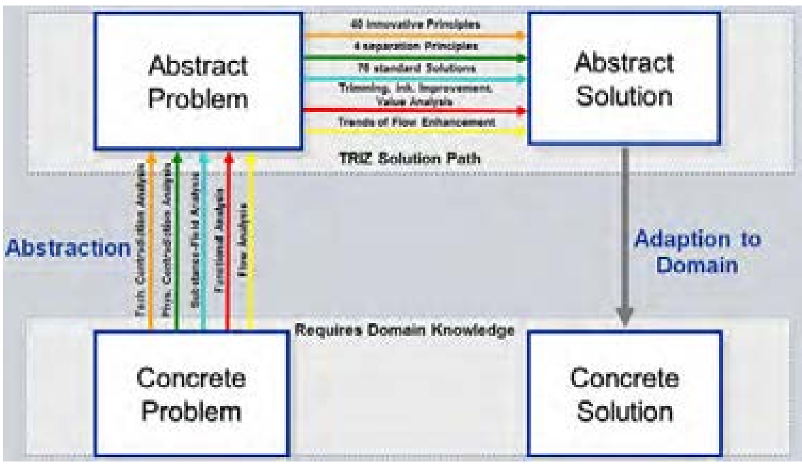


Fig. 4. General TRIZ working model

In recent years TRIZ is increasingly connected with the product and portfolio development process. Ikovenko [14] provides approaches how TRIZ can be applied to develop an existing product portfolio using the MPV thinking of TRIZ and shows how these MPVs can be categorized and used to derive product and portfolio decisions and to find out which product values improvements have the biggest economical potential. Kiesel and Hammer [12] combined TRIZ and Lean methods to improve development processes. In their case study, they demonstrated the impact on the testing time by improving the testing process. To improve the "User Experience" of products, Mayer [13] introduces TRIZ by addressing the nearfield human sensors and proposes to develop them in a structured way.

3. Methodology

The main question of this research is how to combine the Lean and TRIZ approach in a structured way to significantly improve the Lean approach in the field of product development. This paper uses the following approach to answer this question:

1. Categorize different kind of projects in the area of product development
2. Visualize the key methods/ideas/working models of Lean in product development
3. Discuss the experiences applying TRIZ methods in this different project types
4. Attach TRIZ methods into the Lean working models

The concepts of combining Lean and TRIZ tools were applied in 12 different projects in the motion control area and covered following topics:

- innovation of a drive-based motion controller
- improving the Testing Process for SW and HW-related products [12]
- developing and improving a Test Architecture for Test Automation auf motion control products
- improving the usability / user experience of an digital drive by optimizing the Object Model
- Root Cause Analysis and definition of improvement measures for a critical project

To evaluate and specify the combination of TRIZ and Lean related to literature the explored projects are categorized in the following way:

- **process improvement projects** (e.g. improvements within the development, improvements of technical processes)
- **innovation projects** (e.g. for improving specific features/MPVs of a product, for leveraging a new upcoming technology in products)
- **portfolio development processes** (e.g. for structured portfolio development)

The combination of TRIZ and Lean methods has been applied for the different project types. TRIZ tools were used context and situation specific where appropriate Lean tools were missing. To limit the scope, we focused on the most frequently used Lean and TRIZ tools (see table 1).

Table 1

Most frequently used Lean and TRIZ tools

Lean Tools	TRIZ Tools
Hoshin Kanri	RCA (Root Cause Analysis)
A3-report	Ideality
Value Stream Mapping	9 Window / Multi-Screening
Stakeholder Map	Technical and Physical Contradictions
	TESE
	Innovation Situation Questionnaire

4. Results, Implications and Discussion

4.1 TRIZ methods in this different project types and the usage of the TRIZ methods

Table 2 summarizes the impact of using the TRIZ methods in the different project types. For improvement projects, there is a high impact for RCA/RCA+ and Ideality, followed by problem solution tools. Ideality and TESE works best for innovation projects. All others have a medium impact. Within portfolio development projects, Ideality, 9 Window/Multi-Screening and TESE works best. RCA/RCA+ and Innovation Situation Questionnaire have a medium impact. problem solution tools have only a low impact.

Table 2

TRIZ methods applied in a Lean product development context for different project types (0: small impact, +++: high impact).

	Improvement projects	Innovation Projects	Portfolio development projects
RCA / RCA+	+++	++	++
Problem Solution Tools	++	++	+
Ideality	+++	+++	+++
9 Window / Multi-Screening	+	++	+++
TESE	+	+++	+++
Innovation Situation Questionnaire	+	++	++

Implementation of TRIZ methods

The **RCA** tool is very similar to the Ishikawa and the 5-Why method used in the A3-report of Lean. **RCA+** can bring in added value because it models the value parts in the problem chain. Moreover, RCA is helpful for all kind of projects, especially important for improvement projects.

Problem solution tools (e.g. Physical Contradiction, Technical Contradiction) (see figure 1) provide an added value by providing methods for a structured solution finding process. These methods can be used to elaborate possible target states and measures in a guided process. The combination with the 40 innovative principles brings in a good coverage concerning possible solutions. The TRIZ tools bring in a structured solution finding process providing different approaches for problem modeling and problem solving (see figure 4) and provide empirical technical evolution knowledge derived from analyzing thousands of patents. In addition, a Stakeholder Map (method from system architecture) was used. This has proven to be helpful for solving Physical Contradictions. Every stakeholder represents a specific relation. This fits perfectly to the resolution of Physical Contradictions using “separation in relation”.

Ideality is helpful for all kind of projects and is similar to the target state thinking of Lean. It can be used as an opposite perspective to the problem oriented perspective of a Root Cause Analysis. The problem vs. ideality perspective is helpful for thinking in different directions (pain-/gain-driven thinking). In Innovation projects evaluating Ideality “what new useful functions are introduced vs. harmful functions” helps to get a better understanding whether the intended innovation level is big enough related to the effort introduced

TESE (Trends of Engineering System Evolution) are especially helpful for Innovation and Portfolio Development Processes. The method can be applied to visualize the current state concerning the technical evolution state. The current state can be used to derive improvement hypothesis which can be tested as experiments in short PDCA cycles. Innovation ideas can be verified whether they are compliant to the expected next step concerning development of the product or service.

9-Window / Multi-screening can be applied for all project types but it is especially helpful for defining target states for longer (>= 3 years) time periods. It is an easy to apply method and provides a structured approach for finding a good target state for the product / component / process under consideration. It has proven to be very helpful to model the supersystem and the subsystem because this leads to a more holistic thinking. Related to our experience this is a good approach to extend the solution space.

Modeling the current state and the past provides insights in typical evolution patterns taking place and can be used in combination with the TESE method to forecast / derive a hypothesis for the next typical evolution step of the product ("voice of the product"). Modeling the competitor in the supersystem has proven to be interesting to have a specific perspective comparing your forecast to the offering of the competitor.

Innovation Situation Questionnaire is especially helpful for the Innovation and Portfolio Development Processes. It provides a guided and systematic view on the problem. Especially the following aspects have proven to be helpful:

- available resources: Which resources are available? How can they be used?
- What changes are allowed?

4.2 The Lean working model enriched with TRIZ methods

Figure 5 shows the experienced usage of TRIZ tools for different target states and for the PDCA cycle in the Hoshin Kanri process. RCA+, Ideality and Physical Contradictions support the Starting Point and the PDCA cycles best. For a target state, the blue sky and to generate a Northstar, we recommend the TRIZ tools Ideality, 9-Window, TESE and Innovation Situation Questionnaire.

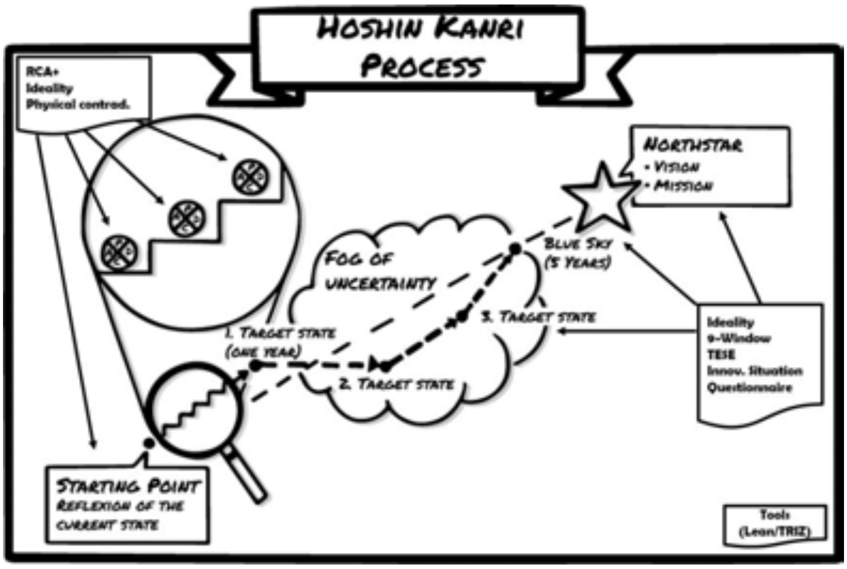


Fig. 5. Applying TRIZ and Lean tools in the Hoshin Kanri process

Looking at the specific areas of the A3-report TRIZ methods can be used to clarify the content (see figure 6):

Lean and TRIZ provide similar methods for problem analysis. TRIZ provides with RCA+ [15] a more sophisticated view on the problem analysis because it visualizes not only the problem chains but also attached value. Lean provides no methods to derive the goals (which are not related to the problem analysis) for the different time scopes of Hoshin Kanri in a structured and methodological way. This is the area where TRIZ methods and TRIZ Thinking can bring in an additional value. Moreover, TRIZ supports the process of transforming problems into solutions with Physical and Technical Contradictions and provides methods for deriving new ideas with the TESE approach (identifying the current state of the system and deriving typical next evolution step). Figure 6 visualizes the usage of TRIZ/Lean tools in the context of an A3-report.

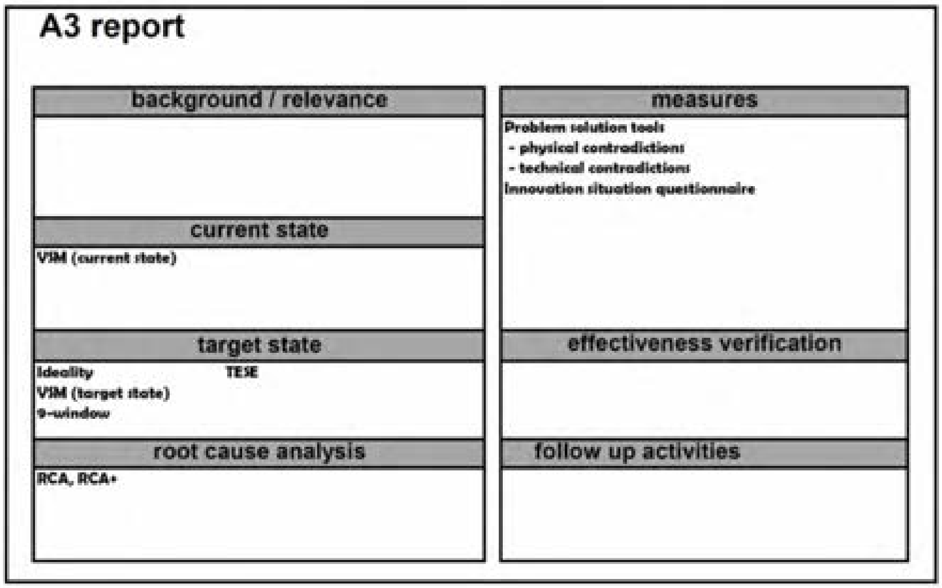


Fig. 6. TRIZ and Lean Tools used in A3-report

5 Conclusion

Related to literature, the impact of using TRIZ (Lean) in different types of projects increases the process success. Moreover, Lean and Agile thinking belong together and both, the product and the requirements are refined through experience. The usage of TRIZ Tools in the Hoshin Kanri process and the underlying PDCA cycle has proven to be very helpful and generates value add in different fields. It enables a more holistic view on the future development. The addition of a broader environment in space (supersystem, subsystem) and time provides insides in changes and clarifies the picture of promising development directions. Looking at changes in resources provides opportunities to lift functionality to a supersystem level. The TESE helps to derive hypothesis in a promising system development direction. TRIZ Tools applied in the context of an A3-report are helpful to generate a broader solution scope by including to the environment and the next evolution step (TESE). Finally, problem solution tools like Physical and Technical Contradictions help to derive measures for the next improvement step. A combination of Lean and TRIZ approaches in a structured way significantly improves the Lean approach in the area of product development. However, it depends on different project types and tasks, which method leads to a success and which not.

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BECOME USER OF TRIZ TOOLS INSTEAD TO PLAY HIDE AND SEEK

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Abstract

The only possible solution for improving the dynamic properties of a car has long been considered to be optimization. Unfortunately, this results in compromise: either an optimal family car, or an optimal sports car. Now, however, developers are making an increased effort to move away from the previous approach of looking for compromises towards the advanced application of their knowledge and use of innovations which can be considered as the unwitting use of trends and patterns of technology development. The challenge for breakthrough perfection of the dynamic properties of a car is to overcome the contradiction between ride comfort and driving safety and to achieve the best possible ride comfort and driving safety simultaneously. An expert on cars, who works without knowledge of the TRIZ approach, draws upon only his area of knowledge, therefore he tries to remove a local conflict (physical contradiction) through new resources (additional equipment to produce force) which results in high value but also unwanted complexity and high costs. This paper presents a case study which showed that improvement of the dynamic properties of the car achieved through the use of TRIZ tools is more effective than the current deployment of expensive raw power. An expert on the TRIZ approach has the mission of guiding the car expert on how to intentionally search for initiatives in successful patents from all areas of knowledge and warns that the removal of local conflict must to take advantage of local resources (drive and braking torque) which makes it possible to achieve high value at low cost. This article aims to convince innovators that, when they will intentionally use TRIZ tools, they enhance the effectiveness of own expertise and diligence.

Keywords: ride comfort, driving safety, TRIZ tools.

1. Causes, needs and tools for perfection

1.1. Epochal discovery

From time immemorial, people have tried unwittingly (without knowledge of laws) improve creations (products and processes) and among random successful cases which originated by way of trial and error, they were searching for "miraculous" common procedure.

Altshuller's epochal discovery of invention patterns under the laws of technology improvement (1946) was essential for understanding how to detect and creatively exploit previously hidden interdisciplinary context (TRIZ: the inventive problem solving theory), [1].

According to a contemporary vision, the driving force behind all the actions (framing, development and demise) in nature is the ubiquitous attraction of perfection-ideality expressed in the form of the Law of perfection: Value = Function / Cost, (Maupertuis, 1746: The Law of least action), [2]. The Law of perfection was scientifically confirmed when Carnot in 1824 described the cycle of a perfect-ideal heat machine, which has the greatest possible (maximum) theoretical efficiency, and according to the second law of thermodynamics pronounced in 1850 by Clausius, it has zero disorder (entropy).

Thus, everything in nature (a great example is the brain) has an innate desire to get as close as possible to the unreachable goal, which is perfect efficiency as a result of perfect usefulness and perfect economy (zero effort and outcomes).

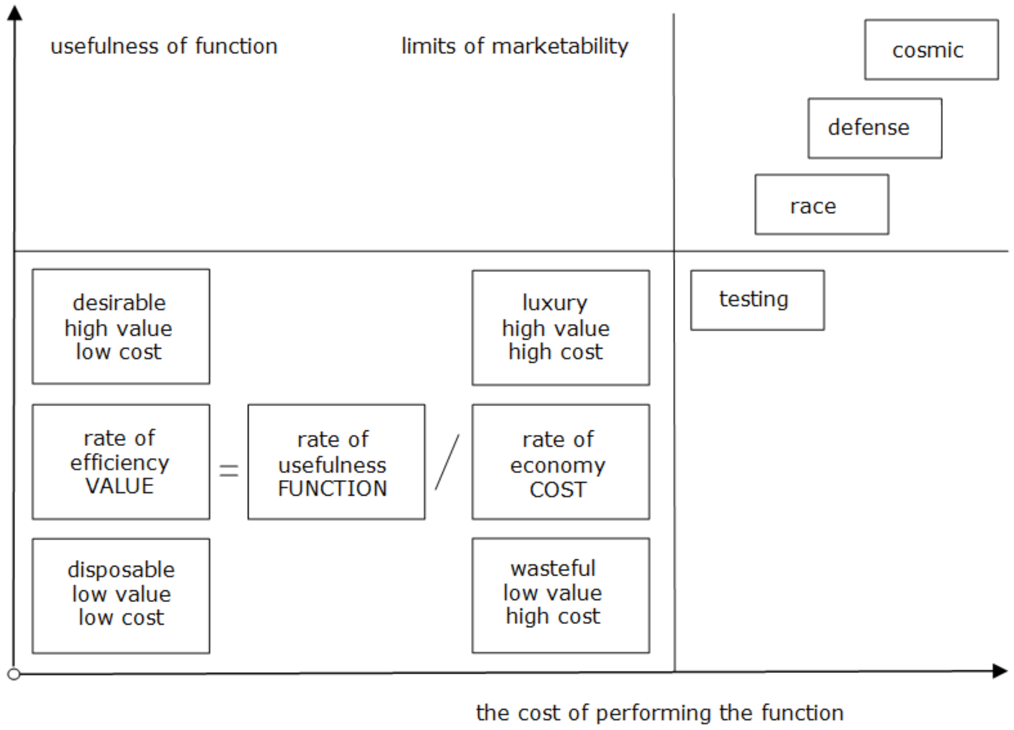


Fig. 1. The value of creations is a measure of their cost effectiveness in fulfilling of their function

The right innovations with the correct properties are popular and successful because they are economical, efficient and effective. They provide a lot for little and make good use of resources, so they are cost-effective for the purchaser (right needs) and are effective for the manufacturer (right goals).

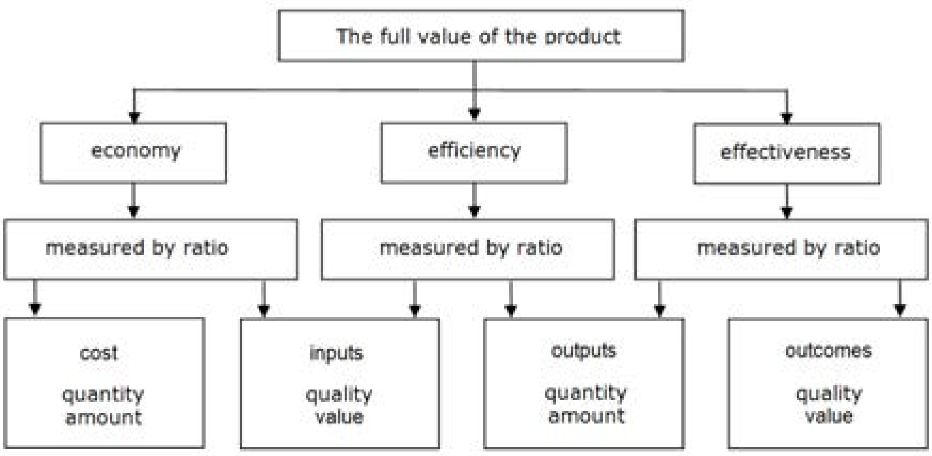


Fig. 2. The full value product is excellent (economical, efficient and effective)

1.2. Surprising results from brain research for the TRIZ approach

The mystery of the miracle of the emergence of something from nothing (the emergence of the universe) by the influence of the ubiquitous attraction of perfection in the form of the Law of perfection of the creators and creations contains in itself the emergence of the sub-consciousness from matter (the emergence of the life-body aspect), the emergence of consciousness-feelings from the stimuli (the emergence of self-consciousness-thinking aspect) and the emergence of the super-consciousness-conscience from the desire for perfection (the creation of love-the spiritual aspect), while love is a manifestation of humility.

The TRIZ approach today is both science and art, which is in line with the laws of development-perfection of advanced logical thinking (dialectics), (Petrov 2002), [3]:

- the law of the unity (interpenetration) of opposites (contradictions);
- the law of transformation of quantity into quality (S-curve); and
- the law of the negation of the negation (spiral development, fractal vortex).

The worldwide initiatives (USA, EU, Japan, China) to advance brain research have these goals:

- the discovery of ways to improve the diagnosis, prevention, and treatment of brain disorders;
- the theoretical modeling of the brain and the development of brain-based artificial intelligence to improve computers;
- the integration of neuroscience with social and behavioral sciences to improve education, life management of a society and creative inventive thinking.

The Nobel prize for the discovery of the collaboration of sentient thinking in the right part of the brain with considering thinking in the left part of the brain obtained Sperry in 1981, [4].

Kahneman was awarded the Nobel prize in 2002 for discovery of slow and painful thinking in the upper part of the brain: neocortex (cerebral), and quick and easy thinking in the lower part of brain: limbic system (basal), [5]. There is lot of scientific evidences (superior pattern processing among others) in the article [6] that development of the brain follows the law of perfection.

Based on results from brain research Fig. 3 depicts a generic pattern of the consecutive steps to deliberately improve conscious thinking about creations taking suggestions from the sub-consciousness and inspiration from the transcendental super-consciousness (meta-cognition).

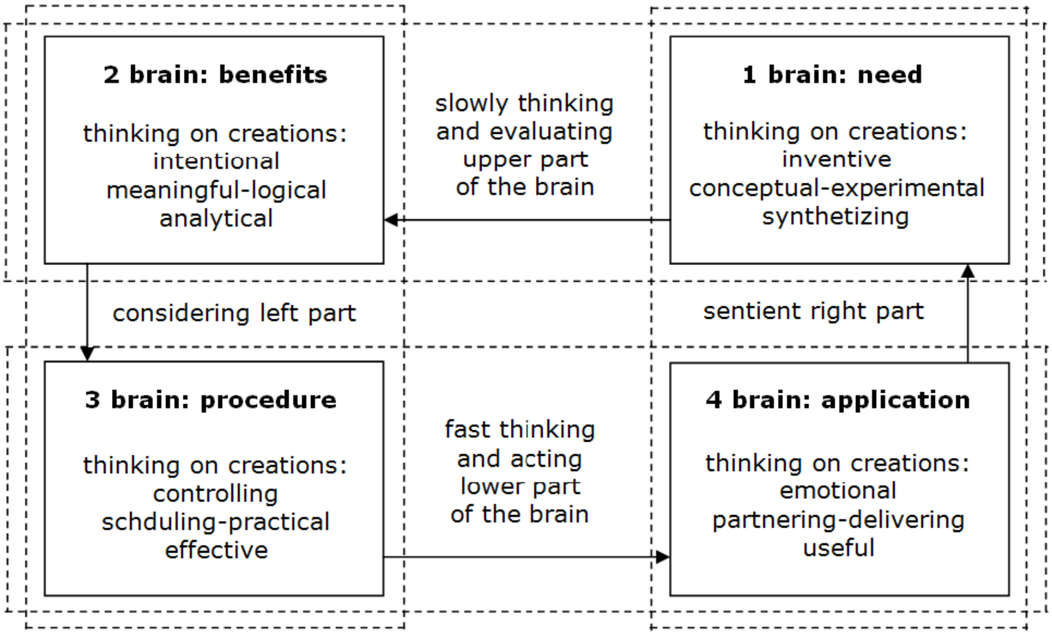


Fig. 3 A generic pattern of consecutive steps for the perfection of conscious thinking

One of the most important result from brain research is that the level of maturity of thought and communication (IQ-intelligence quotient) is inherit and remains almost the same throughout life, with an influence of only 25% on the ability to solve tasks.

So, the European Commission for Education recommended replace the inefficient ways of teaching in the schools via creative thinking [7]:

- 25% of the time should be given to development the expertise and perception of speech:

  (IQ-intelligence quotient),

- 25% of the time should be given to the development of mature toughness and will:

  (AQ-adversity quotient),

- 50% of the time should be given to the development of the perception of images and the ability for collaborative relationships:

  (EQ-emotional quotient), due to critical capability for successful solution of tasks, while it can be significantly increased using suitable exercise (developing the creativity using the TRIZ approach).

1.3. Perfection of knowledge

Thanks to the extraordinary increase in access to knowledge through the Internet, it is important to have a wider knowledge of the context of each instruction (everything is related to everything, the interdisciplinary approach). Not only does the value of knowing for the present (what is needed today) become important, but also the ability to predict the development of knowledge (what will be needed) and to be prepared for it in time.

When we consider acquiring knowledge from successful patents, the abstraction of company expert knowledge is a process involving knowledge transformation in which the real or quantitative attributes are replaced by abstract or qualitative attributes. As a result of this transformation, the transformed knowledge together with knowledge from outside of the company becomes applicable to a much larger class of systems than the original systems that provided the initial knowledge, [8]. The TRIZ approach enables identification and structuring of the knowledge in order to facilitate innovation. A generic pattern of the knowledge life cycle with consecutive steps to purposefully perfecting knowledge according to the TRIZ approach is in Fig.4.

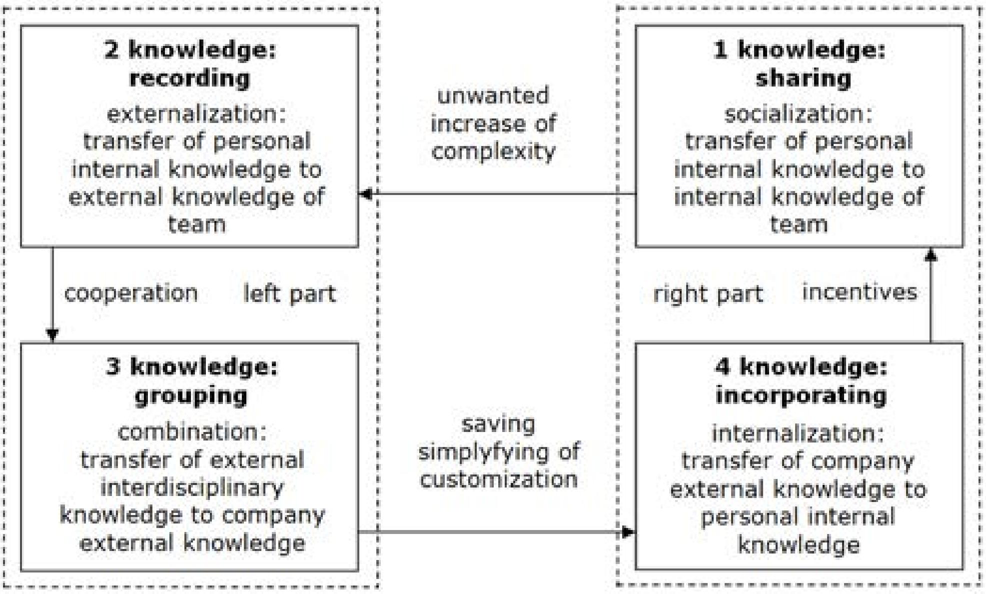


Fig. 4 A generic pattern of consecutive steps for the perfection of knowledge

The generic pattern of knowledge sharing is a cycle starting with the transfer of personal knowledge to the internal knowledge of a team, which we denote as socialization. The creators can practically share their unique experience of creating, when they put tacit experience into clear terms, rules and techniques based on the objective laws of the TRIZ approach.

The second step is externalization: the transfer of personal internal knowledge to the external knowledge of the team which can be recorded as the intellectual property of a company.

In the third step, a combination takes place: the transfer of external interdisciplinary knowledge to the company′s external knowledge by means of collaboration with an expert from outside of the company under the supervision of TRIZ expert.

The fourth and final step (internalization) concerns increasing the usability and the level (quality) of personal knowledge by customizing-adapting the company knowledge.

2. TRIZ approach for perfecting the dynamic of the car

2.1. Conflict-contradiction between ride comfort and driving safety

Vehicle suspension system performance is typically rated by its ability to provide improved road handling (driving safety) and improved passenger perception of oscillation (ride comfort), [9]. The fixed setting of passive suspension properties is always a compromise between ride comfort and driving safety for any given road conditions on the one hand, and payload suspension parameters on the other. When engineers attempt to improve the car′s driving comfort (A) so that no sudden changes in the position of the car body (under minimum acceleration), this deteriorates driving safety (B) in the form of undesirable jumps of the wheels. The traditional approach to improving engineering systems through optimization within their design concept without knowledge of the TRIZ approach allows only small and vulnerable improvements which are valid only for a narrow variation of the initial properties and results in unwanted compromises. Hence we have the concept of the family car that has good ride comfort (A_D) in Fig.5a, but poor driving safety (B_Z) and the sports car that has good driving safety (B_D), because it maintains the wheels in constant contact with the road (without jumps), but it has poor ride comfort (A_Z).

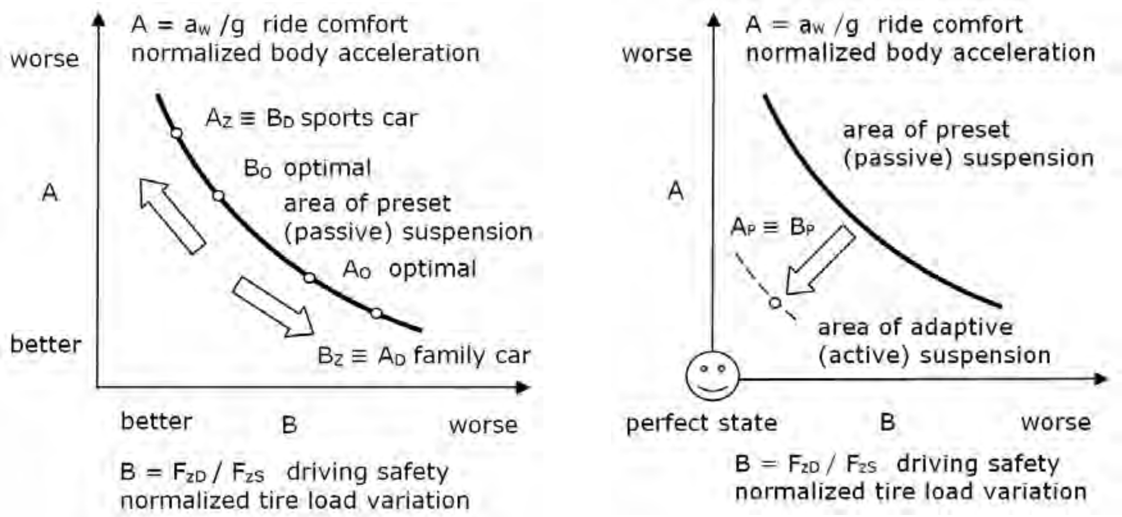


Fig.5 Target conflict-contradiction between ride comfort (A) and driving safety (B) for a) passive suspension, and for b) active suspension

The main objective of suspension systems is to reduce the movement of the car body (sprung mass). Therefore, the challenge to achieve a breakthrough perfecting the driving performance of a car is to overcome the contradiction (opposing ride comfort and driving safety), and to achieve the best possible ride comfort and driving safety ($A_P \equiv B_P$) in Fig.5b simultaneously.

2.2. Improvement of car without knowledge of the TRIZ approach

An expert on cars who works without knowledge of the TRIZ approach uses only his area of knowledge, therefore he tries to remove a local conflict through new resources (additional equipment to produce force). The result is a luxury car of high value but high costs (Fig.1). A Magic Body Control system [10] with a camera which scans irregularities in the road ahead. Then the Active Body Control system [10] uses a hydraulic piston to act on each steel coil spring to quickly and independently adjust the suspension on each wheel and provide the best possible ride comfort and driving safety ($A_P \equiv B_P$) on Fig.5b simultaneously.

Fig.6 a) Magic Body Control system and b) Active Body Control system

2.3. Perfecting of car using the TRIZ approach

Each problem is unique and needs an expert of TRIZ approach to interpret the knowledge from other areas (out of the box) to understand the language of the company expert and to adapt his knowledge to a new individual application. Knowledge management moves from the purely technological into the area of mature relationships and cooperative culture (Fig.7). So, the solution to knowledge management is more cultural than technological.

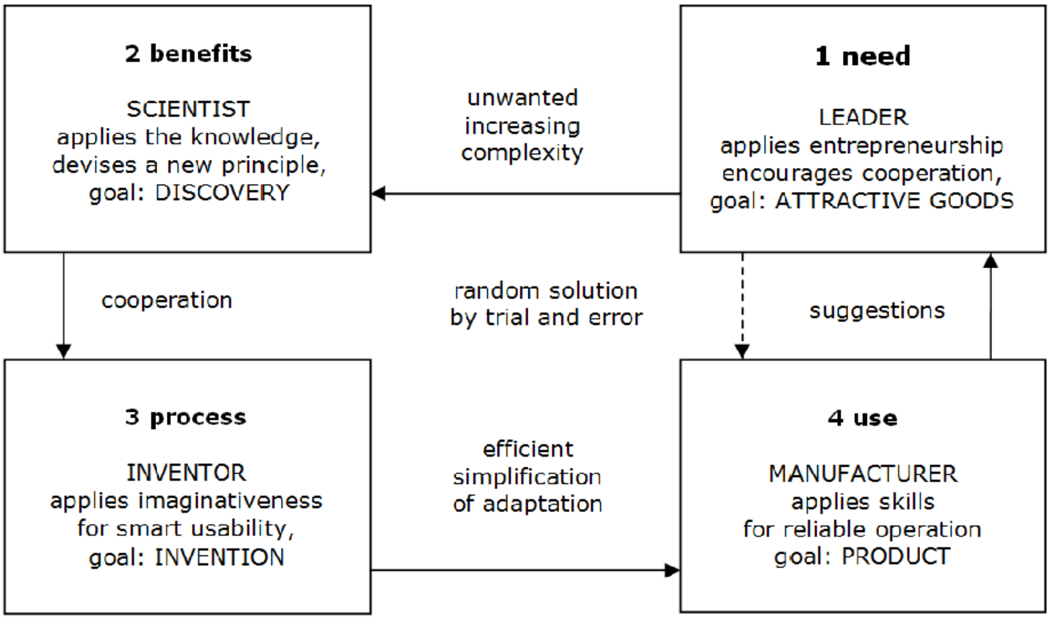


Fig.7 A generic pattern of consecutive steps for systematic cooperation

In the TRIZ approach the essence of the generic pattern of consecutive steps in Fig.8 (need, benefits, procedure, and use) for systematic perfection of vehicle dynamic properties: ride comfort (A) and driving safety (B) is to recognize and solve (overcome, remove) contradictions, [11].

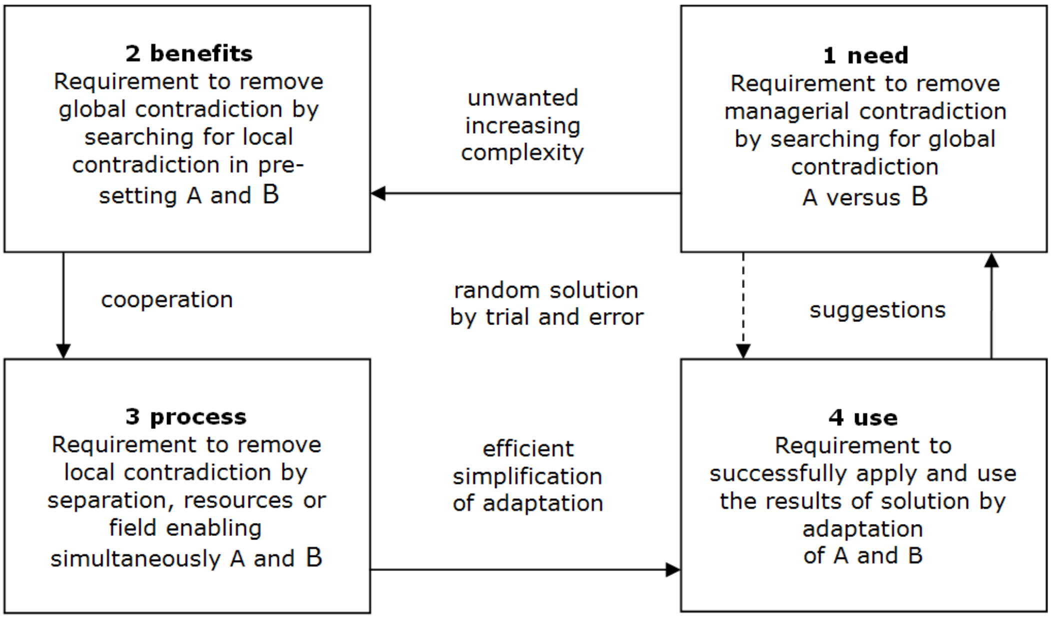


Fig.8 A generic pattern of consecutive steps for the perfection of creations

Step 1 - Why? analysis of challenges (need)

When the need arises to overcome market opponents or resolve a customer's requirement, the leader-manager fist defines the managerial-administrative contradiction on the level of intention for a change. This is the contradiction between the requirements to improve the car and the absence of the conditions to do so (need to identify the targets, acquire knowledge of the process and ensure proper resources). The principle for overcoming the managerial-administrative contradiction is to seek out and remove the global-technical contradiction.

Step 2 - What? do the right things (benefits)

The global-technical contradiction at the system level of creation is the conflicting relationship between the features of the parts of the whole creation when improving one part: ride comfort (A) at the level of car body it worsens the second part: driving safety (B) at the level of the wheel.

The overall principle for overcoming this global-technical contradiction is to search for and remove the local-physical contradiction.

Step 3 - How? do things right (process),

The local-physical contradiction at the single part (suspension) level: the suspension of the car body must ensure zero change in the force transmitted to the car body for its desirable zero heave, and at the same time to ensure non-zero change in the force which pushes the wheel onto the road. Then the car can provide the best possible ride comfort and driving safety ($A_P \equiv B_P$) on Fig.5b simultaneously.

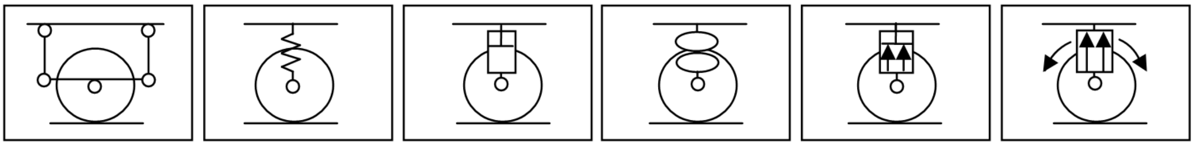
The physical contradiction can be solved (overcome, remove):

- by separation of conflicting requirements: in space, in time, on conditions, and substitution,
- by use of resources: interdisciplinary information, energy, substance, space, effects and time,

- by transition from solid state to the field.

Step 4 - Who? collaborate with right people (use)

The expert of the TRIZ approach has the mission to guide the car expert on how to intentionally search for initiatives in successful patents from all areas of knowledge and to warn that the removal of local contradiction must take advantage of local resources (drive and braking torque) which make it possible to achieve the desired high value at low cost car.



(1) (2) (3) (4) (5) (6)

Fig. 9 The trend of suspension development to the control of driving and braking torque

Fig.9 shows the transition from the preset (passive) features of a mechanical suspension (1), (2) to a hydraulic suspension with self-adaptable change of magneto rheological fluid properties, (3) to a hydro-pneumatic suspension (4), to the adaptable (active) suspension with electronic management of features (5), toward the recent removal of unwanted movements of the car body (vertical heave, yaw, roll and pitch) for desirable ride comfort (A) by quick control of the drive and braking torque acting on the wheel motors using a LEAF system: (Leading Environmental Affordable Family car), [12] and ensuring the necessary wheel load for driving safety (B) simultaneously (6), (Fig.10). This is the evolution of the suspension system to the innovative breakthrough perfecting.

Fig.10 a) torque increase causes raising up the front of the vehicle, b) by torque decrease the front of the vehicle will be lower

3. Conclusions

The exceptional ability of the brain for conscious thinking (in collaboration of consciousness with the sub-conscious and super-consciousness) is associated with its connection to the ubiquitous effect of attraction of perfection.

The current understanding of the ability of the mass to act work (energy and its transformation in the field of mass) makes it possible to imagine the ability of brain to act in the massless field in the form of thoughts, ideas, and information, which is also a manifestation of the ability to act work (energy and its transformation) because the results of its application are advanced properties of creators and their creations.

The TRIZ approach was the result of exploring effective creations (products and processes) to find out which creativity principles were necessary to create these successful creations. Therefore, using TRIZ policy rules, concepts, and procedures allows us to improve the ability to create. The successful creator has the ability to think effectively, act ethically, communicate clearly, and manage efficiently. The efforts made so far to achieve success in the marketplace have mainly been aimed at breakthrough maturity of the products, but they will only be created by a mature creator who has advanced feelings, thoughts and actions, and the breakthrough products will be accepted only by consumers with advanced needs in an environment with an advanced infrastructure.

Our collective understanding of the world is becoming more comprehensive, complex and complete. This means that to carry out their work successfully, engineers have to take into consideration that an efficient way how to stay informed of new and emerging technologies, is cooperation. Digital Embodiment of Function [13] enables to more exhaustively use all new resources of engineering development.

Each successful innovation arises with respect for laws of perfecting, even if innovators working without the knowledge of TRIZ approach are unaware of it. When using the TRIZ approach, the advantage is that the creator achieves his goal more efficiently, with less effort, in less time and making the most efficient use of the resources available under the given conditions. The formula for breakthrough creations = Crazy ideas + Enthusiasm + Laws of perfecting + Collaborative relationships based on the high EQ-emotional quotient (Fig.11).

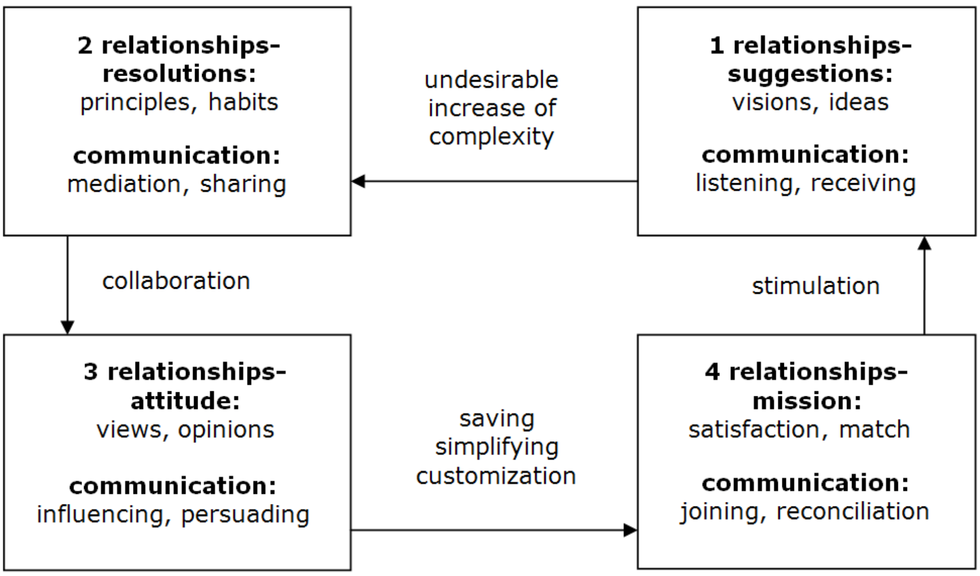


Fig.11 A generic pattern of consecutive steps for the perfection of collaborative relationships

The feedback between innovators, innovations and infrastructure is the mechanism responsible for the evolution of our civilization in the desired direction satisfying our higher needs toward correct relations-values for humble and satisfied coexistence.

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CLOSING THE KNOWLEDGE GAPS

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Abstract

This paper proposes to combine TRIZ with Rapid Learning Cycles (RLC) to create an innovative and suitable tool to help solving problems by inventing ideas and improving them prior to the realization. RLC helps to improve management of problem definition by segmenting the problem and discovering Knowledge Gaps to improve decision making. The approach proposed is illustrated by the case study of testing a new type of electro acoustic transducer.

Keywords: Rapid Learning Cycles; TRIZ

1. Preface

1.1 Introduction

The history of science and engineering is full of "lone wolves" working alone on their inventions. The moment they were ready with their discoveries was the moment of introducing them to the market. Currently the freedom of inventing was replaced with the hard work of development. There is no more space for unrestricted by time process of thinking. Sales organizations are driving the product cadence which forces the product introduction to the market at certain date e.g. to catch the Christmas sales. Also, the market life of the product is shorter.

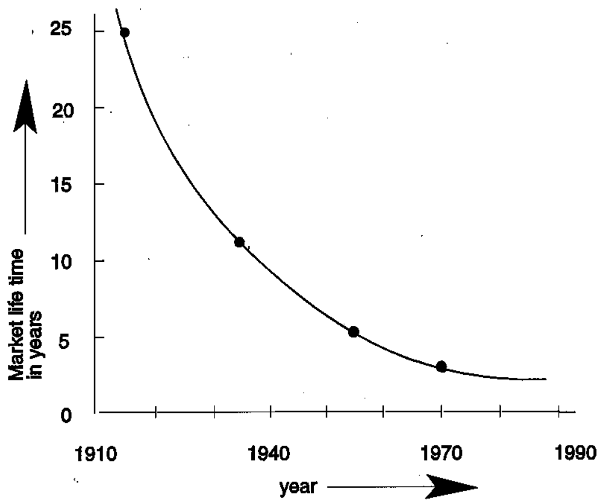

Figure 1. Market Life of Industrial products (Andreasen & Hein 1987)

1.2. The Problem

TRIZ works best when the problem can be well defined, and the contradictory factors/process parameters can be identified. It means that improvement of existing systems is a perfect subject for TRIZ approach- we can always imagine the “smart little people” modelling the solution, or brainstorming guided by the TRIZ matrix. But the use of TRIZ for problems where the solution has to be created from scratch is limited. In the article authors describe the process of creation of the measurement station for the specific type of electro acoustic transducer. This type of transducer was not produced before so the previous experience was not relevant and could even be a constraint when looking for the right solution.

2. Practical use of the combination of Rapid Learning Cycles and TRIZ to develop the measurement system for electro acoustic transducer.

2.1. Rapid learning cycles

RLC was developed by Katerine Radeka and described in a book “The shortest distance between you and the new product”. [1] The method is an answer to the “scientific model” of development. The scientific method is based on stating the thesis and working on confirming or denying the thesis. Unfortunately, proving that the initial thesis is false, may be a scientific success, but usually it is a commercial or engineering failure. In the industry, the feasibility must be concluded or denied as early as it is possible, while decisions should be taken as late as possible. It implies slightly different approach to defining what knowledge we need to gain in order to be able to take the right decisions. The keys to Rapid Learning Cycles are Knowledge Gaps and Key Decisions. The whole process starts with the Core Hypothesis which is similar to the “scientific method”. Key Decisions are decisions crucial for the product shape and parameters. Knowledge Gaps is the knowledge we do not know yet, but is needed to take the right decisions.

2.2 Practical case

The described example of developing the measurement system is a classical engineering problem for each new transducer. The new type usually needs a new approach, but thinking of engineers is affected with the old experience. Quality standards in a hearing aid industry are extremely high, so 100% of transducers must be properly tested before shipping. Quality of parts must be assured by production process, and confirmed by final measurement. This is called FCQ[1]. The standard of consumer electronic is a sample control and statistical data processing. In our case this is not allowed. The mentioned transducer was measured in a traditional way like other transducers used for hearing aids, which resulted in an extremely long cycle time and very complicated handling. The measurement setup consists of the sound source, reference microphone and measurement card (as drawn in the figure below). All the measurement devices

[1] FCQ Final Control of Quality

are placed in a sound isolating enclosure. This is a standard setup for measuring electro acoustic transducers. The challenge is the measurement accuracy, which depends on multiple factors like background noise, position, contact, etc. All of these complicate handling of DUT[2]. In a large scale production, this is simply not acceptable.

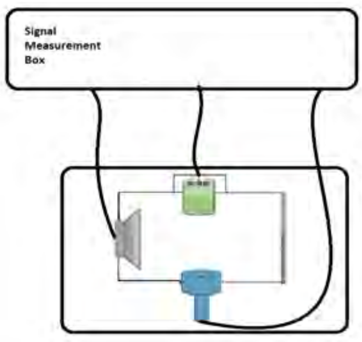

Figure 2. Measurement setup

2.3 Core Hypothesis

The Core Hypothesis is a starting point. It is a vision of the product or the idea defined in short comprehensive words. It may be defined by the project team, given by inventor or management team. In this case the core hypothesis is formulated internally. The "product" presented in the article will not go directly to the market, but is an "enabling technology", allowing staying on the demanding market. The hypothesis was created at the project team meeting during which it was also decided to go with RLC scheme. The decision was taken after couple of unsuccessful brainstorming/TRIZ sessions, which produced several potential solutions, However, the team was not unanimous whether the solutions were optimal. With knowledge on RLC, the team realized that there is unexplored knowledge which may lead to different ways of solving our problem. RLC seemed to be an answer, because both brainstorming and TRIZ are based on synthetic approach to the current level of knowledge of the problem, while RLC addresses knowledge we don't know yet.

The Core hypothesis should *define the* problem under 3 aspects**:** value which customer likes (= want to pay for); the technology which may be enhancing or limiting factor; and business model.

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[2] DUT – Device Under Test

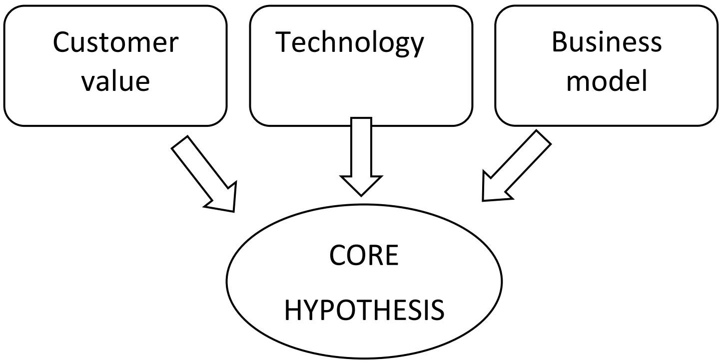


Figure 3. The Core Hypothesis

The core hypothesis was defined by the team: ***"The method of final control of transducers is needed when the labor content is reduced to 30sec per piece, by eliminating then non value adding operations and improving cycle time of other operations."***

In simple words, let us approach the 30 sec. measurement time by eliminating waste. But someone may ask what is waste? Which operations are adding the value and which are not? The Core hypothesis implies the first set of Key Decisions which needs to be taken to meet requirements from the Core Hypothesis.

Table 1

Core Hypothesis evaluation

Customer Value (internal customer- production facility)	Business Value	Technology
Increase of the operator friendliness and productivity Reduction of CT. of all necessary operations like: Unpacking Marking Visual check (at least 1) FCQ Packing	To decrease product cost price. To improve (decrease cycle time) of the longest operations To eliminate the longest and hardest Operations from process flow.	New technology Use technology that allows to eliminate all non-value added operations. Technology must ensure scalability. Preferably without (or with minimum) need of increasing footprint in facility.

2.4 Knowledge gaps and key decisions.

The next action after defining the Core hypothesis is performing an event Kick-Off to define the initial set of "Key Decisions" and related "Knowledge Gaps". Figure 4 shows the result. It is remarkable that one Key Decision requires several Knowledge Gaps to be solved. Solving the problem in the intuitive way, people tend to link a problem with a pre-assumed solution, where all the effort is spent to further develop the solution which came out of e.g. a brainstorming session.

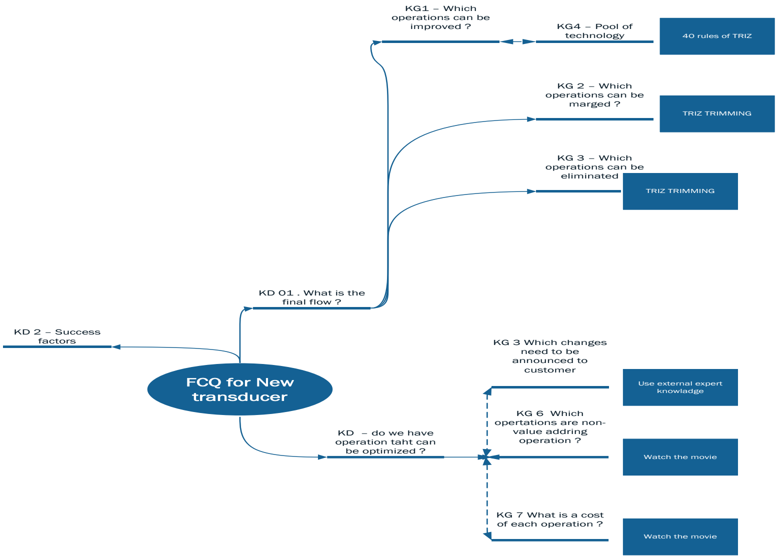


Figure 4. Mind map illustrating key decisions and Knowledge gaps

Figure 4 illustrates the *Knowledge Gaps* and related *Key Decisions* that are needed to solve to find a solution to the problem.

In order to systematize the actions, the *Knowledge Gaps* have been compiled into a table to follow them one by one and assign actions. The necessary data must be filled in in order to solve the knowledge gaps and make Key Decisions.

Table 2

Knowledge gap number	**Description of knowledge gap**	**Action to be taken in order to obtain necessary data and fill the knowledge gap out**
KG1	Which operations can be improved?	TRIZ trimming
KG 2	Which Operations can be merged?	TRIZ trimming
KG 3	Which operations can be eliminated?	TRIZ Trimming
KG4	What are available technologies which are suitable for our needs?	40 rules of TRIZ
KG5	Which changes in a production flow must be announced to a customer?	This KG can't be solved by means of TRIZ tools, but requires aligning with customers on their requirements on their qualification procedures.
KG6	Which operations are non-value adding?	Analysis of movies from production. This is an exercise to see which operations are adding value to the product (are absolutely necessary), like performing the process, inspection etc. While material handling, buffering etc. is considered the non-value adding.
KG 7	How much each operation cost?	GEMBA walk – collecting information on the shop floor: labor consumption, reject, downtime

Knowledge gaps and ways to close them

2.5 Solving the Knowledge Gaps.

As it has been described in Chapter 2.1, Knowledge Gap is the knowledge we don't know yet, but which is needed to take the right decisions. Table 2 shows the result of Knowledge gap definition event. Knowledge Gaps KG5, KG6 and KG7 do not require much thought ("just do it"), so they will not be described in this article, however they have to be solved to obtain a complete set of data for the project.

2.5.1 Solving the Knowledge Gaps KG1, KG2 and KG3 by TRIZ Trimming

These three Knowledge Gaps have a lot in common. The actions of eliminating, merging or improving can be done at the same level. On the other hand, these procedures are also known from Design for Assembly analysis. Some of them may also be improved in the first step. Then they can be merged, however in the end, it may happen that improved and merged operation could be eliminated too. For such an approach, Trimming seems to be a natural tool of TRIZ to use.

The first step was to define all tools (Function Carriers) that are included in the current measurement setup, as shown in Table 3.

Table 3.

Interaction matrix of measurement setup

	DUT	**Operator**	**Jig**	**Jig cable**	**Reference microphone**	**Reference microphone cable**	**Silent box with loudspeaker**	**Sound box (WBT)**	**Speaker in sound box (WBT)**	**Signal measurement box (UTU)**	**Production floor**
DUT		x	x				X	x	x	x	x
Operator	x		x				x	x		x	
Jig	x	x		x			X	x			
Jig cable			x							x	
Reference microphone						x	x	x			X
Reference microphone cable					x					x	
Silent box with loudspeaker	x	x	x		x			x			
Sound box (WBT)	x	x	x		x		x				
Speaker in sound box (WBT)	x									x	
Signal measurement box (UTU)	x	x		x		x			x		X
Production floor	x				x					x	

The next step was to identify an Object and functions between Function Carriers and Object. Function diagram specifies the interactions.

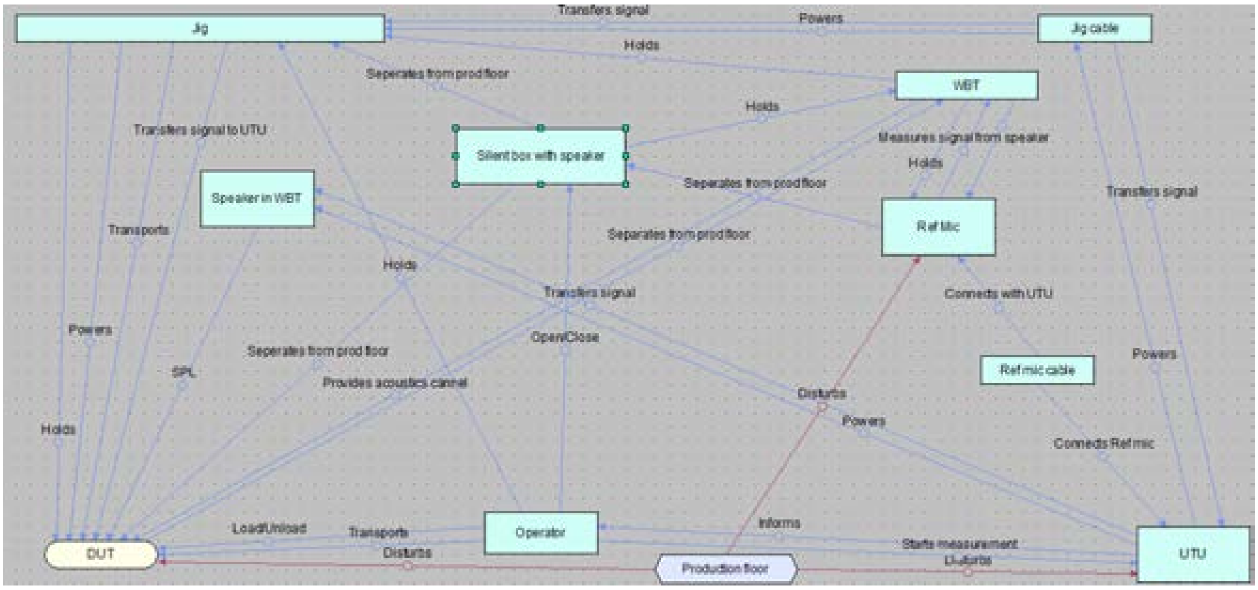
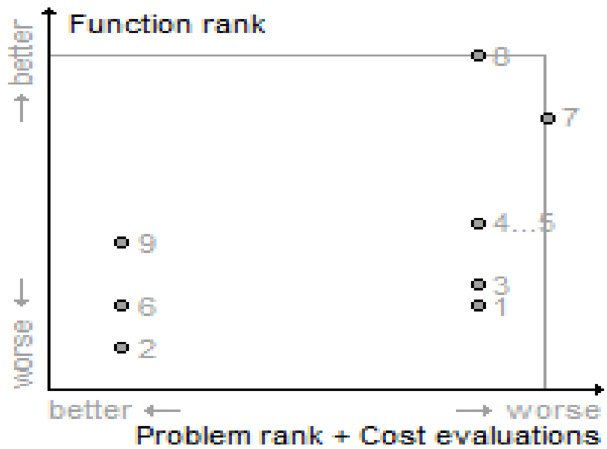


Figure 5. The function diagram

Trimming procedure was conducted in six steps, consisting of improving, merging and finally eliminating some tools (Function Carriers), like Sound box, Sound box speaker and Jig. Using A, B and C rules of Trimming the team achieved 33% of improvement.

Table 4.
Table of ranks of components

Component	**Possible trimming order**	**Trimming Factor F*F/(P+C)**	**Function Rank, F, %**	**Problem Rank, P+C, %**
Speaker in WBT	1	1.04	5.97	15.00
Ref mic cable	2	1.56	2.98	2.50
Jig cable	3	1.63	7.47	15.00
WBT	4	4.17	11.94	15.00
Silent box with speaker	5	4.17	11.94	15.00
Ref Mic	6	6.25	5.97	2.50
Operator	7	9.44	19.41	17.50
Jig	8	16.67	23.87	15.00
UTU	9	19.18	10.46	2.50



Legend

F - function rank

P - problem rank

C - cost evaluation

Figure 6. "Cons and Pros" graph

In the final step the following trimmed function diagram was obtained (Fig. 7).

Figure 7. Trimmed function diagram

Figure 7 shows the result of trimming and suggestions that silent *box with loudspeaker* takes over the functionality of *jig* and *sound box with speaker*. Further steps were taken to define requirements for new integrated box (=silent box with loudspeaker):

- Provide an electrical connection of *DUT*, *reference microphone* and *speaker* with Signal measurement box (*UTU)*.

- Provide acoustic shielding from the production floor.

- Provide an appropriate acoustic canal.
- Provide an appropriate positioning of *DUT*, reference *microphone* and *speaker* in the acoustic canal.
- Provide easy loading of *DUT* into the acoustic canal.

2.5.2 Solving KG4 by TRIZ 40 principles matrix

Knowledge Gap 4 (KG4) led us to look at what technologies are available which are suitable for our needs. This gap was defined in the previous map of actions (figure 3, table 2), so we expect it will guide us to the particular Parameters to improve our measurement system.

TRIZ 40 Principles Contradiction Matrix suggests to cross two parameters. However, it is not easy to find such pair and match a problem. Surely, there are several potential assumptions of possible contradictions, but we had to choose the one we were thinking would be the most appropriate to our application. So we did the following:

Accuracy of measurement – undertaken in order to prevent any setback.

Exploitation, Versatility, Complexity and Level of automation – applied for the improvement of the process.

Table 5.
Contradictions table.

To prevent setback		Accuracy of measurement
To improve		28
33	Facilitation of application	25, 13, 2, 34
35	Versatility	35, 5, 1, 10
36	Complexity	2, 26, 10, 34
38	Level of automation	28, 26, 10, 34

We have analyzed all matching principles and decided to go with three of them:

- ***Exploitation vs Accuracy of measurement***
    - ***Principle 25: can we automatize the process?***

      Yes. The automatization of the process is common in high scale electronic component production where pick'n'place machines are in use.

- ***Versatility vs Accuracy of measurement***

  - ***Principle 1: can we divide the process?***

    Yes. The action of measuring requires *Silent Box* to separate *DUT* from the external noise. It is applicable only when the *Measurement System* measures internal noise of *DUT* which is lower than noise generated by the external environment (*production floor*). Other parameters such as sensitivity, impedance, etc. do not require separation form external noise. We used to keep *DUT* in the *Silent Box* throughout whole measurement process. Due to a fact that the procedure was performed in the manual mode it was natural to carry the whole measurement by one handling. If an automated machine handled the operations, the processes might be separate. All parameters, excluding noise, are measured in the automated equipment. After measuring a whole batch of *DUT's,* we will move it to the next station, where there will be a "cheap" silent box which will measure internal noise of *DUT*.

- ***Versatility/Complexity/Level of automation vs Accuracy of measurement***

  - ***Principle 10: what can we do ahead of measurement operation?***

    One of the most time consuming operations is placing *DUT* in a holder equipped with a nest providing an appropriate electrical connection. The cheap plastic holders, which are used as carriers, were designed. Operator places *DUTs* in the carriers in the operation prior to the measurement. In the next step, the carriers containing *DUTs* are loaded into the measurement machine. The machine is equipped with a measurement head with a *speaker*, *reference microphone,* and the *electrical pins* providing connection.

The final flow of the measurement process will contain three major operations:

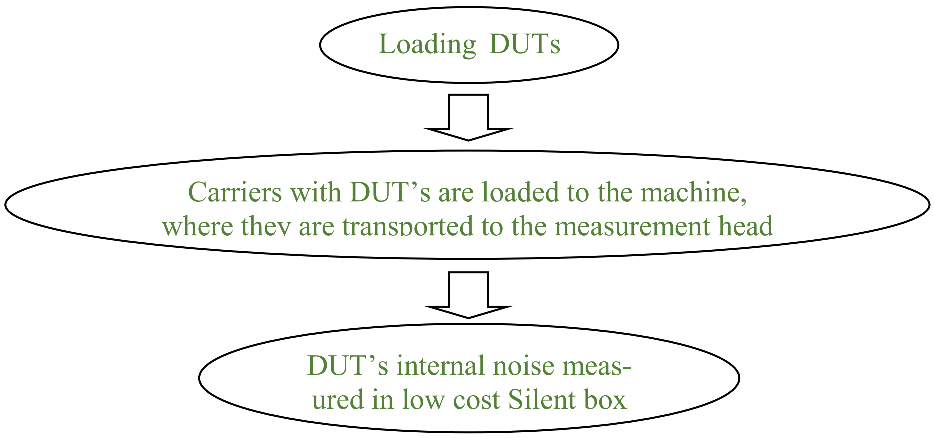


Figure 8. Proposal of measurement flow

The next step was to make a concept of technical solution and illustrate it:

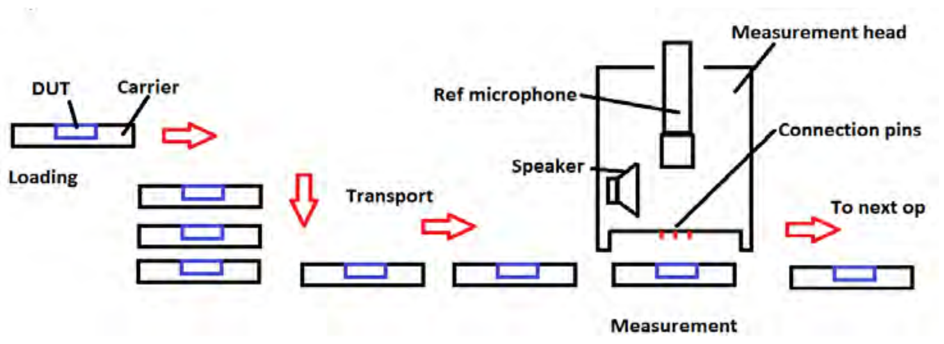


Figure 9. The concept of measurement flow in automated machine, the illustration of process flow

2.5.3 Approaching the final solution – taking Key Decisions

We successfully finished the process of closing the *Knowledge Gaps*, so we could move on to the *Key Decisions* to attempt to answer *What is the final flow?* and to *build a prototype machine* which later became a part of production equipment and significantly improved a process of measuring the electro-acoustic transducer. This is how the final production machine looks like (there is no noise measurement implemented with separate silent box, still under construction):

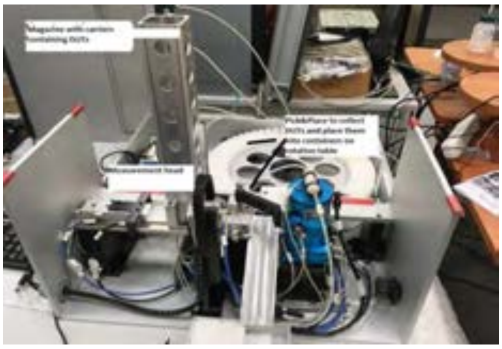


Figure 10. Measurement machine designed and build by Sonion

3. Discussion

The case study described in the article addresses a common problem solved in production environment. A new product requires a new approach for measurement, quality control etc. The old method usually can be applied but it is not optimal for the new product. The difficulty lies in defining the boundary conditions. Usually, the “old” method constrains people from finding a new, optimal solution and preventing major breakthroughs. A resistance must be overcome by various creative methods. The one, which is used the most commonly, is “brainstorming”. However, it is very rare to obtain positive results. In the case described in the article, the brainstorming session brought a set of ideas. It was, however, extremely difficult to assess which ideas were worth undertaking and which were not. The brainstorming is a shortcut between the non-fully recognized problem and the solutions that are ready to implement. The result is a product of luck, mood of participants, and their experience. There is no stimulus for creativity. In the mentioned above case, the generated ideas were very much an evolution of the previously used methods. Actually it was difficult to judge if all the options were explored, while the feeling of the team was that it was not.

The process of creative thinking is complicated and human dependent. Same people may produce different results while being in a different environment. Methods such as TRIZ add guidelines to the process of thinking so that the most optimal results can be discovered. Alternatively, to the combination of RLC and TRIZ, a “direct TRIZ” could have been used, without all the hassle of defining knowledge gaps and key decisions. The interesting outcome of RLC process is the multi-level knowledge gaps. Closing of the initial set of gaps created the next ones also closed by TRIZ. Of course, the iterative process could happen without the RLC, but there was no guarantee.

While comparing the approach with a “direct TRIZ “, the most obvious contradiction seems to be the improvement of the processing speed without compromising the automation level. It leads to Principles 6 and 10: multi functionality and prepared action. It directs to the conclusion on merging some operations, or preparing a microphone in a measuring jig “offline” in order to minimize the idle time.

4. Conclusions

Comparing the direct TRIZ with RLC/TRIZ approach is like swallowing a big chunk of problem vs. dividing the problem into smaller pieces. RLC allows to digest the problem and generate couple of smaller tasks. TRIZ can be run several times instead of once, which seems to give better results.

Another conclusion is that knowledge gaps are well formulated questions, which can be answered by experts from other industries, particularly if one can isolate them from the industry specific “distractors”.

This article proves that TRIZ with combination of Rapid Learning Cycles method might be an innovative and suitable tool to help solving problems by inventing ideas and improving them prior to the realization. In the first phase, the idea comes from RLC method, but it may not be optimized. TRIZ, on the other hand, helps us to make it simpler and easier to realize, which allows to cut corners and costs of the equipment or the process when it’s still on a “paper”.

Acknowledgements

ODiTK TRIZ Trimming, ODiTK TRIZ 40 Principles Matrix

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COMBINING THE MORPHOLOGICAL ANALYSIS WITH TRIZ: THE INDUSTRIAL USE CASE

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Abstract

For more than one century distribution transformers have played a major role in the electric system. They provide the final voltage transformation, reducing the voltage used in the distribution lines to the level used by the customer. This simple purpose defines also the basic design of the product, which remains unchanged for decades already. The stable design allows for optimization of the manufacturing processes and high quality production, but on the other hand – the constant tendency for energy, material and cost savings facilities application of new design methodologies, such as TRIZ, for example.

In the presented paper, authors combined the TRIZ with a morphological analysis (a method proposed by Fritz Zwicky for exploring all the possible solutions to a complex problem). Since the first method provided the general design recommendations ("The other way around", for example), the later technique allowed to systematically explore all possible design concepts for the object being investigated. The paper describes the industrial use case – the study on the design of a distribution transformer. Thanks to the applied methodology it was possible to define a "Zwicky box" – the morphological matrix offering a number of new design variants (16, in this particular case). Some of the new proposals were next manufactured and tested, what finally allowed to create a number of new patent applications.

Keywords: TRIZ, morphological analysis, Zwicky box, transformer design, industrial use case

1. Introduction.

Since 1882, when an electric system using distribution transformers was demonstrated for the first time, these components have played a vital role in the electric power distribution organism. They provide the voltage transformation, reducing the voltage used in the distribution lines (normally up to 60 kV) to the level used by the customers (normally below 400 V). This simple purpose defines also the basic design of the product, which remains unchanged for decades. In addition, the traditional and stable design allows for optimization of the manufacturing process and reliable, high quality production. However, the permanent tendency for energy, material and cost reduction inquiries the review of existing design by applying TRIZ, for example. This paper describes the analysis of the distribution transformer design, and provides the structured approach allowing to find out new, original arrangement of transformer's components. The presented method utilizes TRIZ to generate innovative principles, and general morphological analysis to systematically explore potential solutions. The article is structured as follows. The theoretical background of the study, focused mainly on transformer design and the principles of the morphological analysis, is given in chapter 2. The details of the industrial use case are given in next section, while the chapter 4 provides short summary.

2. Theoretical background of the analysis.

2.1. Transformer design

A basic design of 1-phase transformer consists of two coils that are electrically separated and inductive, but magnetically linked through a path of reluctance. The main operation principle is the mutual inductance between coils, which is realized by the magnetic flux flowing within the laminated steel core. In this way a simple, static device can transform electric power from one circuit to electric power of the same frequency in another circuit. In the case of 3-phase system, the typical transformer features three cylindrical coils and respective planar magnetic core, *Fig. 1*. Naturally, the device also needs some suitable container for the assembled core and windings, and the isolation medium (not shown in *Fig. 1*).

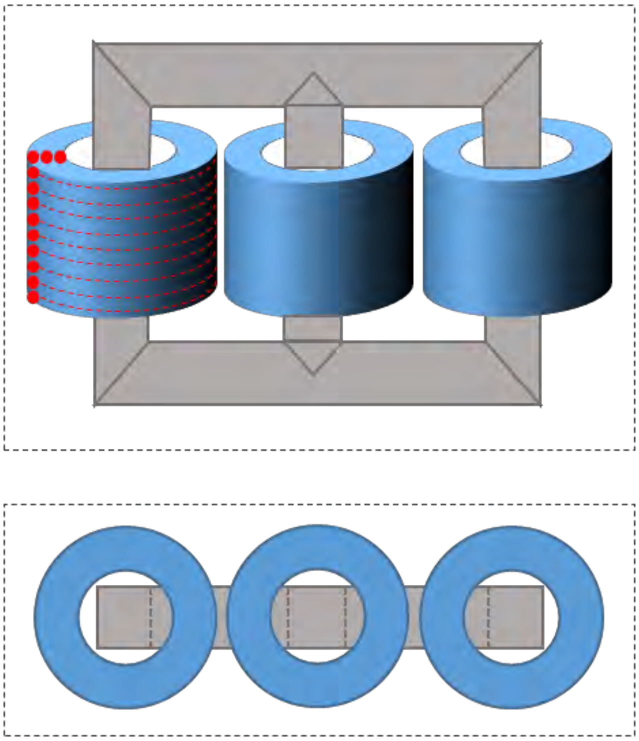

Fig. 1. Schematic representation of active components in 3-phase electric transformer: planar magnetic core made of laminated steel, and cylindrical coils made of copper (or aluminum) wires.

In the classical solution the coils are wound around three vertical columns (known also as “legs”), which are joined together by two horizontal yokes. Both columns and yokes are made of thin sheets of magnetic steel, and they form a laminated core. The coils consist of high voltage (HV) and low voltage (LV) windings made of copper or aluminum wires. The magnetic core and coils form so-called “active parts” of the transformer (they transform electro-magnetic energy) - in contrast to the remaining components, which are used only for isolation (cellulose, oil) and mechanical support (external tank, clamping beams).

Because the basic arrangement of the typical transformer is known for decades the respective manufacturing process could be heavily optimized. Naturally, this positively influences the quality and reliability of the final product, but - on the other - it prevents more innovative design. In order to find out new innovative principles for transformer design, the TRIZ and morphological analysis were involved. Since the first method is quite well recognized within the industry, the next paragraph will shortly cover the morphological analysis only.

2.2. Morphological analysis by Fritz Zwicky

Despite its delightful name Morphological Analysis works through very simple processes, using two common principles of creativity: (I) decomposition and (II) forced association. The problem is first broken down into component variables and possible values identified for each variable. The association principle is then brought into play by generating multiple combinations of these values. The combinations are organized in a morphological matrix, therefore all potential solutions are visualized, and all design concepts could be systematically analyzed.

The method was invented by Fritz Zwicky, the Bulgaria-born, Swiss astrophysicist and aerospace scientist, during his work at the California Institute of Technology (Caltech) in 1966. Zwicky aimed to structure and investigate the total set of relationships contained in multidimensional, non-quantifiable problems, which can be met in diverse fields of science. He applied the method into the classification of astrophysical objects, the development of jet and rocket propulsion systems, and the analysis of legal aspects of space travel and colonization. But not only. When researchers talk about neutron stars, dark matter, and gravitational lenses, they all agree that Zwicky noticed these problems in the 1930s. He had discovered more supernovae than everyone over else in the human history combined, [1].

Essentially, Fritz Zwicky proposed a generalized form of morphological research. The term “morphology” comes from Greek (*morphe*) and means *shape* or *form*. The general definition of morphology is “the study of form of pattern”, for example the shape and arrangement of parts within an object. The method identifies and investigates the total set of possible “configurations” contained in a given problem complex. The matrix presenting all possible combinations – known as a “Zwicky box” – is contracted by setting the parameters (dimensions) of the problem against each other. One can imagine for example, the research on a vehicle design. The problem could be described by three design parameters (dimensions): the number of wheels {1, 2, 3, 4}; the position of passengers {sitting, standing}, and the use of the engine {engine applied, no engine}. Combining these 3 design parameters and their 4x2x2 “values” one could theoretically generate 16 different design concepts. For example: {one wheel, standing position, no engine}; {two wheels, standing position, with engine}, {three wheels, sitting position, with engine}, … . Naturally, the combination of parameters, letting to uncover the multiplicity of the relationships, is nothing spectacular and was used far before Zwicky. However, thanks to his highly systematic approach to multidimensional problem structuring, Zwicky turned general morphology into a discipline in itself, [2].

3. The industrial use case.

When applying TRIZ technique into the systematic analysis of transformer Weight reduction problem, one can specify three contradicting parameters: (I) the Intensity - understood here as a magnetic flux density, or (II) the Area - which contributes to the flux density, or (III) the Stress – understood here as an electrical stress within the components. But basically, all three scenarios (Weight vs. Intensity, Weight vs. Area, and Weight vs. Stress) return the same inventive principles: “Parameter Change”, or “The other way around”, or “Flexible”, [3]. The suggestion provided by TRIZ specifies clearly that design parameters, understood also as an arrangement of the components with a transformer, should be investigated. And this design domain is a natural arena of the morphological analysis, as proposed by Zwicky.

To start with the morphological analysis one has to define the design parameters (known also as *variables*, or *dimensions*). In case of the typical transformer it is very useful to note that:

1) the magnetic core is planar, and the core components (columns and yokes) are arranged in one plane;
2) the magnetic core is made of flat laminations;
3) yokes and columns are straight;
4) columns are parallel to each other, and the footprint is rectangular.

Having these remarks in mind, and remembering the inventive principles provided by TRIZ ("The other way around", "Flexible") one can formulate the following design parameters and their "values":

1) **Geometry of the transformer: {Planar, Spatial}**
   – it describes the geometrical arrangement of the transformer components, if they are organized in one plane (flat), or spatially (as suggested by "The other way around" principle);
2) **Laminations: {Stacked, Folded}**
   - it refers to the arrangement of the laminations within the core, which could be either stacked (flat, as today), or folded, bended (as suggested by "Flexible" principle);
3) **Yoke angle: {Straight, Rounded}**
   - it characterizes the design of yokes, which could be straight (as today), or rounded (according to the "Flexible" principle);
4) **Footprint: {Star, Delta}**
   - it describes the way how yokes are connected. Three yokes can either be connected in the central point forming "Star" arrangement, or they can directly link two neighboring columns (Delta footprint).

Having 4 design parameters, and 2 values for each variable, one can theoretically generate 16 (2^4) different design concepts. The graphical representation of the "Zwicky box" created for the analyzed transformer is shown schematically in *Fig. 2*.

(1) Geometry ⇨			Spatial		Planar	
(2) Laminations ⇨ (3) Yoke angle ⇩			*Folded*	*Stacked*	*Folded*	*Stacked*
(4) Footprint ⇨	Delta	*Rounded*	*„I"*	*„V"*	*„IX"*	*„XIII"*
		Straight	*„II"*	*„VI"*	*„X"*	*„XIV"*
	Star	*Rounded*	*„III"*	*„VII"*	*„XI"*	*„XV"*
		Straight	*„IV"*	*„VIII"*	*„XII"*	*„XVI"*

Fig. 2. The morphological matrix for the analyzed distribution transformer.

For example, the design concept marked as "V" represents transformer with spatially distributed columns, build in stacked technology and having rounded yokes which form Delta arrangement. Similarly, the design concept marked as "VI" features spatially distributed columns connected by straight yokes, *Fig. 3*.

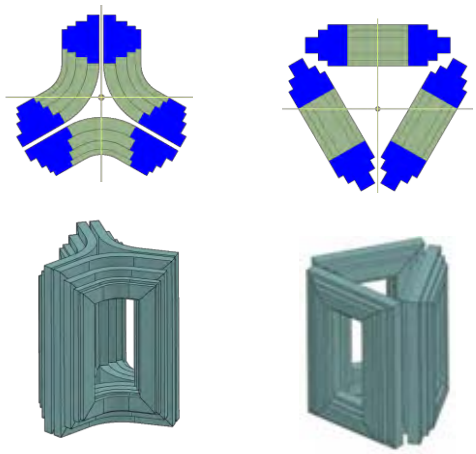

Fig. 3. Some of the possible design concepts for analyzed transformer featuring Delta footprint: version “V” - rounded yoke (left), and “VI” - straight yokes (right). Magnetic core shown only (coils not visualized).

Analogically, the transformer design concepts offering “Star” connection are shown in *Fig. 4*.

Fig. 4. Some of the design concepts for analyzed transformer featuring Star footprint: version “IV” – folded technology (left), and “VIII” – stacked laminations (right).

Quite interesting design concepts can be generated if one utilizes “The other way around” and “Flexible” principles, as suggested by TRIZ. If the columns are not arranged as parallel anymore, and additionally, some of the elements are treated as flexible (e.g. bent or deformed), the transformer versions as shown in *Fig. 5* could be easily provided.

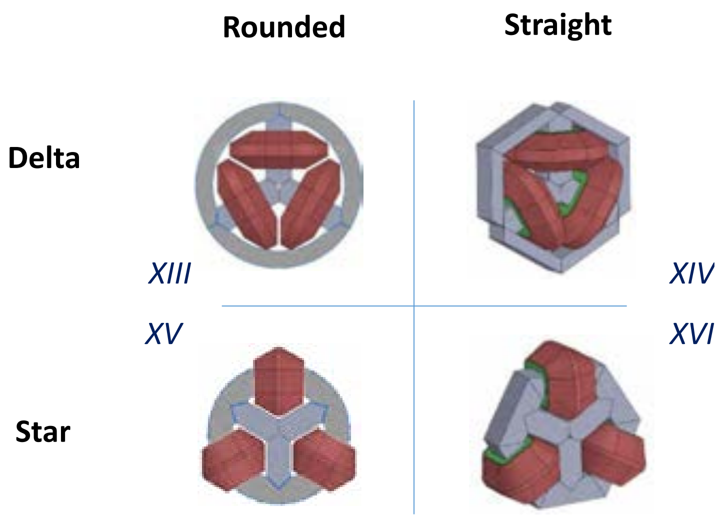

Fig. 5. Possible variants of analyzed transformer featuring “Ring core” design: versions “XIII” – “XVI”.

It has to be pointed out, that the systematic analysis of the transfer design, which was enhanced by TRIZ methodology and morphological matrix allowed to discover many nontrivial design configurations. Some of the concepts (as schematically named in *Fig. 2*) were then verified, manufactured, and tested, *Fig. 6*. It basically allowed to evaluate all the production aspects of the proposed solutions.

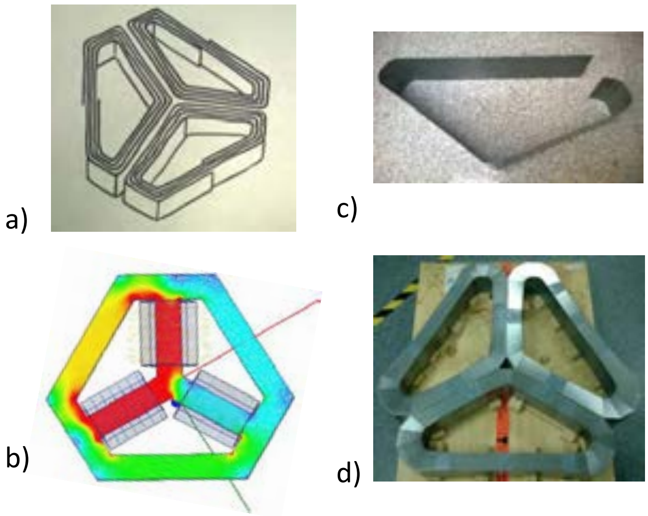

Fig. 6. The exemplary verification process for the design variant "IX": a) graphical representation of the idea, b) FEM analysis of the electro-magnetic behavior, c) a single metal sheet after folding, d) the whole magnetic core assembled.

Since most of the design concepts were positively verified (the manufacturing process was feasible and the design concept basically worked), the respective patent applications could be submitted, [4-5].

4. Conclusions.

When introducing the TRIZ method into the Weight reduction problem of real products, one can face the difficulty in the application of "The other way around" principle. Especially for standard, very typical and well established designs, the novel geometrical arrangement of the components may be not trivial. In this context the systematic study of the problem offered by the morphological analysis and the "Zwicky box" may be treated as a good support for the TRIZ. The practical introduction of both tools (TRIZ and morphological matrix) into the real, industrial case of distribution transformer allowed to reveal a number of new design variants and unobvious configurations. It created the basis for very methodological study of this particular design problem, and provided the method for patents generation.

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CONSTRUCTION OF INNOVATIVE ECOLOGICAL ENVIRONMENT OF COLLEGE STUDENTS BASED ON TRIZ THEORY

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Abstract:

Aimed at exploring how to use TRIZ theory as a guide, construct campus collaborative innovation environment to effectively promote the application and innovation abilities of college students .Using TRIZ theory in college students' innovative training model, is the application of TRIZ in management problems. Analyzed the problems of the current college students' innovation activities running with the causal chain tool. Captured key reasons that Innovation activities in college running effect is not ideal. Applied Sub-field Model method in the management mode of innovative training, and established Sub-field Models of key problems for Innovation activities. Then according to the General solution, put forward the countermeasures. The article suggests that the smooth innovation activities should be a process of continuous cycle, form closed cycle chained mode as Selection of goals-Creative design-Harvest fruit-Transformation of achievements- Selection of goals.

Then combined the innovation process chain with the Sub-field models, we can get an Innovation cycle system, in which TRIZ theory is the core. It means that the study and application of TRIZ theory plays an important role in the whole innovation cycle. Formed a collaborative innovation system composed with teacher and student stratification, college and university stratification, and social stratification. Combined Industry-University-Research for Innovation and described it as Ecological environment of innovation which provided a model for the sustainable development of university innovation activities.

Keywords: TRIZ; Collaborative innovation; Innovative ecological environment

1.Introduction

Innovative ability is very important to a nation, and cultivating college students' innovation ability is an important task for higher education.Although Various types of College Students' scientific and technological innovation training have made certain achievements, but it should also be noted there are problems that float on the surface or hidden behind. Such as training efficiency of college students' creativity ability is low, and translating innovation into practical productivity is hard.

The problem of university students' scientific and technological innovation activities running belongs to management problem. Researching on the innovative training mode of college students with TRIZ is its application in management. Not only helps to build a new management model, but also to explore the theory of TRIZ.

2. Analyse the problem of the low running efficient of innovation activities with the Cause chain

Cause chain is a process to analyse the problem through the multi-level intermediate problems. In this way, the surface problem is transformed into a series of deep-seated problems,to realize and find the key reasons, which are helpful to find approach to solving .

In this paper, we analyse why innovation activities in college running effect is not ideal with the causal chain, to find the key reasons, see Fig. 1.

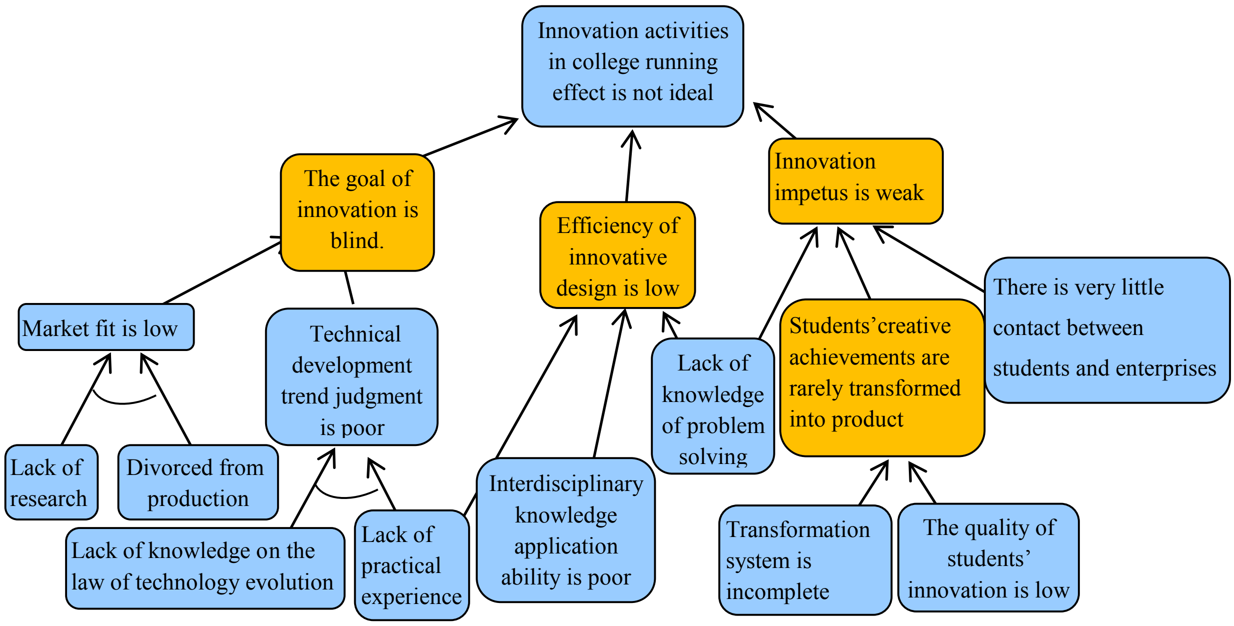


Fig1. Causal chain analysis

Through the causal chain analysis, we can see the key reason why innovation activities in college running effect is not ideal.

2.1 Out of touch with the actual production, the direction of innovation is fuzzy

In college,students neither be in touch with the actual industrial production, nor be familiar with the process of industrial production. So their technical development trend judgment is poor and the direction of innovation is fuzzy. They often determine by subjective judgment leads to the goal of innovation is blind.

2.2 With blind process, College Students' efficiency of innovative design is low.

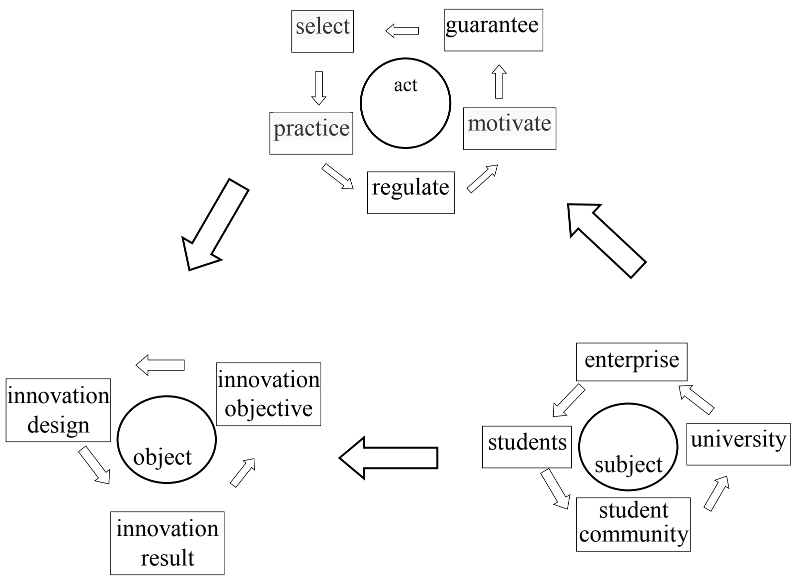
The process of College Students' scientific and technological innovation is blind, mainly comes from imitation .They can not focus on technical system contradictions, make use of resources insufficiently , so that College Students' efficiency of innovative design is low.

2.3 With deficient science and technology innovation mechanism, the innovation achievements of college students are rarely translated into products

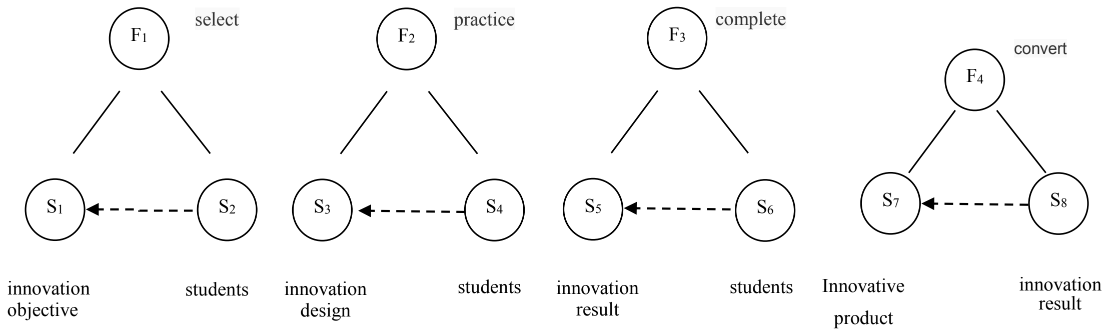
There are several factors and bottlenecks, incomplete students innovation system , lacking investment of technology and education , less the direct contact between students and enterprises. As a result, driving force of innovation is weak.

3. Build Sub-field models of key reasons, seek countermeasures with general solution for reference

In TRIZ theory, the object field model is a very important tool to solve the problem. The core idea is to solve the problem of sub- field model with the general form. We tried to apply Sub-field model method in the field of management, the concept of substance and field can be broadly defined. In this paper, some factors of innovation activities are abstracted as "tool substance"-S2, such as students, TRIZ courses, enterprises, student communities, university,etc. some factors of innovation activities are abstracted as " Object substance"- S1, such as innovation objectives, innovative design, innovation result, etc. The management measures is defined as "field". Thus, established sub-field models of the innovation activities of College students.



Corresponding to core problems analysed with causal chain analysis, we established Sub-field models.



General solution is an effective tool to generate Countermeasures.

Table 1

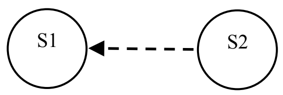
General solutions

Insufficient Sub-field model	General solution
	Replace F_1 with another field F_2
	Use another substance S_3 instead of S_2 or S_1
	Adding a field F_2
	Adding a substance S_3 and adding a field F_2 to form a chain structure

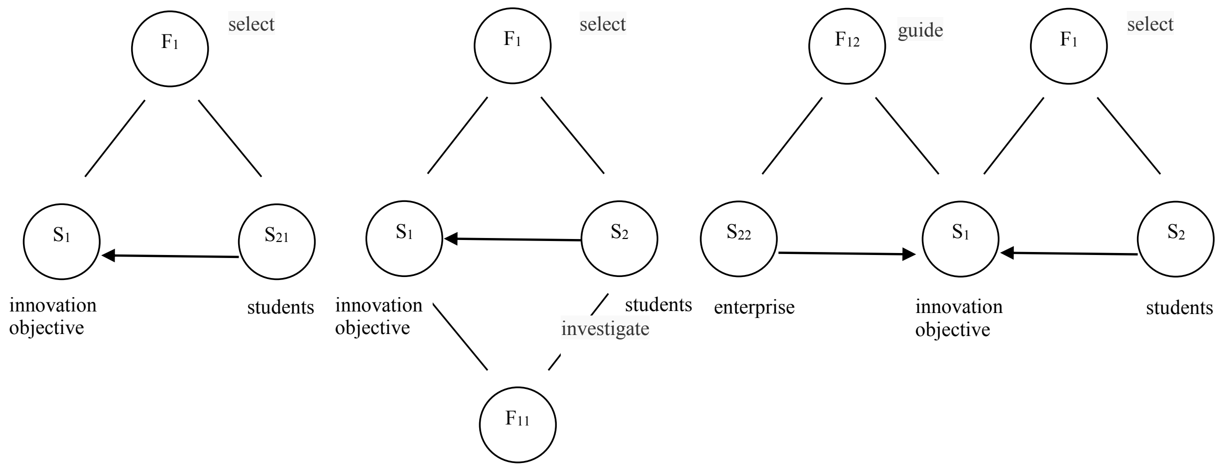
Aimed at the problem that the students select innovation objective, and innovation direction is fuzzy,we put forward corresponding countermeasures.

Table 2

Countermeasures of students -innovative objective

	General solution	Countermeasures
 innovation objective students	Use another substance S3 instead of S2 or S1	Let students learn TRIZ then master the law of technical development, so that they will be good at looking for innovative objective. Instead $S_2$with S_{21}.
	Adding a field F2	Pay attention to market research F_{11}, Help students find innovative needs.
	Adding a substance S3 and adding a field F2 to form a chain structure	Invite experts guidance to help students find innovative goals.the S_{22}&F_{12} joined to model .

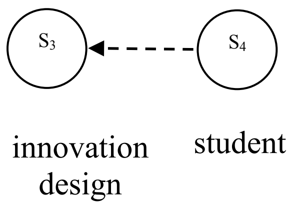
The countermeasure Sub-field model is formed as follows：



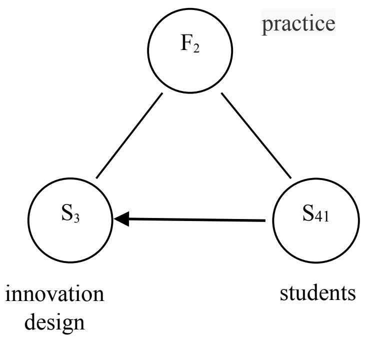
Aimed at the problems in the process of creative design, we put forward corresponding countermeasures.

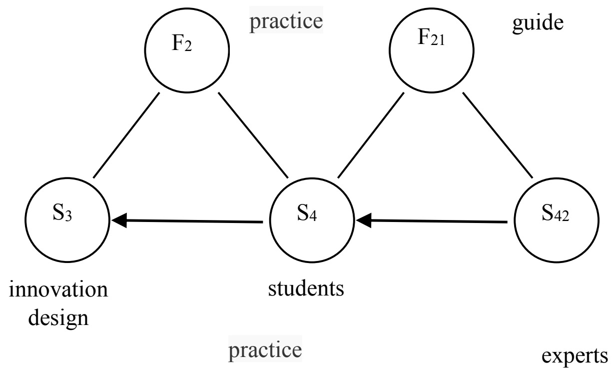
Table 3

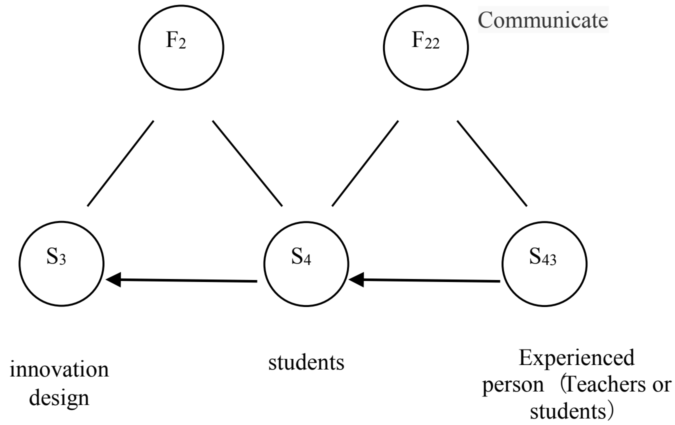
Countermeasures of innovative design process

	General solution	Countermeasures
	Use another substance S_3 instead of S_2 or S_1	Let students learn TRIZ, and use innovative tools solve problems.Instead $S_4$with S_{41}.
	Adding a substance S3 and adding a field F2 to form a chain structure	Invite experts guidance to help students normalize innovative process. S_{42}&F_{21} joined to model .
		Ask experienced teachers and students to impart experience , promote innovation efficiency.S_{43}&F_{22} joined to model .

The countermeasure Sub-field model is as following：





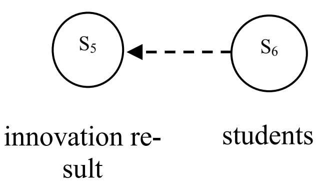


Aimed at the problem that quality of students' innovation is low, put forward corresponding countermeasures as following.

students

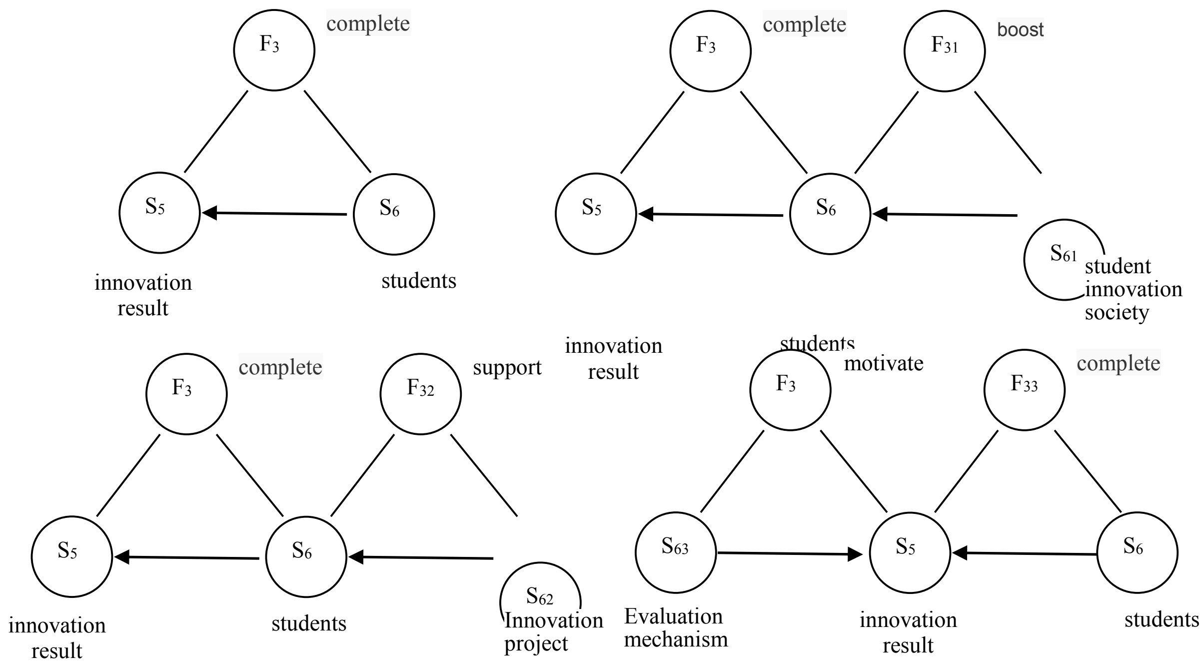
Table 4

Countermeasures of the problem that quality of students' innovation is low

	General solution	Countermeasures
	Use another substance S3 instead of S2 or S1	Let students learn TRIZ, to stimulate their innovation power. Instead S_6 with S_{61}
	Adding a substance S3 and adding a field F2 to form a chain structure	Establish a student innovation league S_{51}, through developing league's activity,boost innovative interest
		Apply National Undergraduate Innovation Project S_{62}, grant funding to support F_{31}. Ensure the continuity of innovation activities

		Establish evaluation mechanism S_{63}, drive to improve the quality of F_{32} innovation

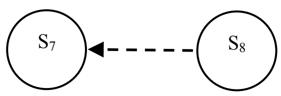
The countermeasure Sub-field model is formed as following：



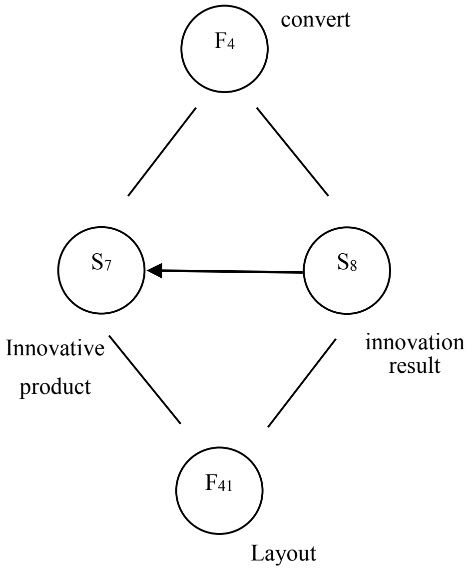
Aimed at the problem of low conversion rate of College Students' innovative achievements.

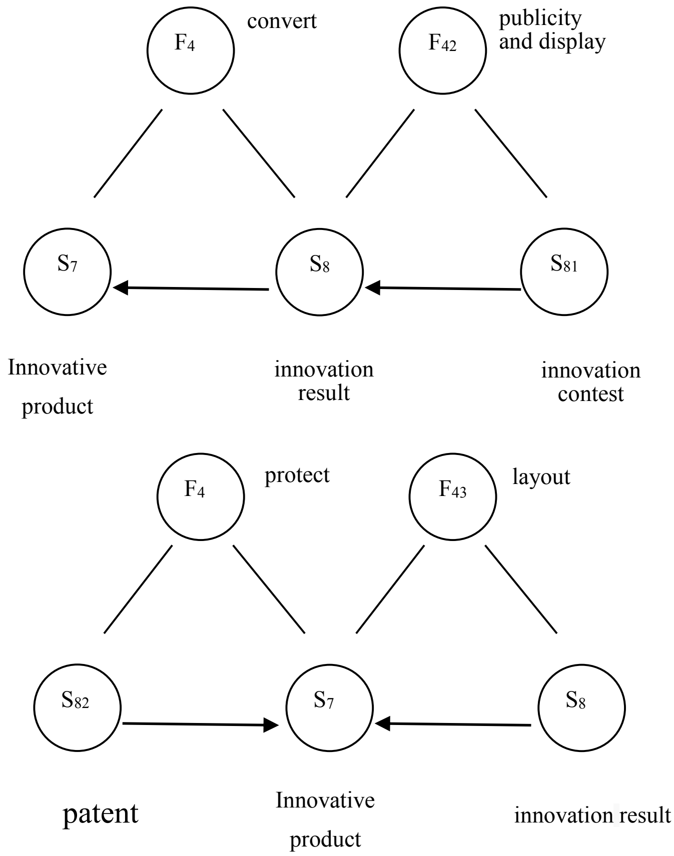
Table 4

Countermeasures of the problem of conversion rate of students' innovative achievements is low

	General solution	Countermeasures
 Innovative product	Adding a field F_2	Make patent layout strategies with TRIZ, and improve the efficiency of transformation. (F_{41})
	Use another substance S_3 instead of S_2 or S_1	Encourage students to enter innovation contests (S_{81}), publicity and display innovation results (F_{42})
		Encourage patent application (S_{82}), strengthen the protection of intellectual property rights (F_{43}).

The countermeasure Sub-field model is formed as follows：





We see Sub-field model is beneficial for management generating strategy .

4. Construction of collaborative innovation mechanism, formed innovative ecological environment

Efficient innovative activities for College Students is a closed cycle. From innovative object, innovative design, innovative result, to the product and then back to innovative object, see Fig. 2.

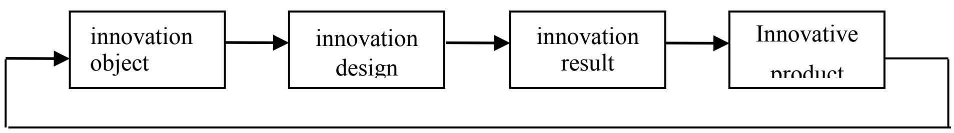


Fig 2. Innovation process chain

Combined the innovation process chain with the strategic model, we form a closed loop system. We call it "innovation ecosystem", see Fig. 3.

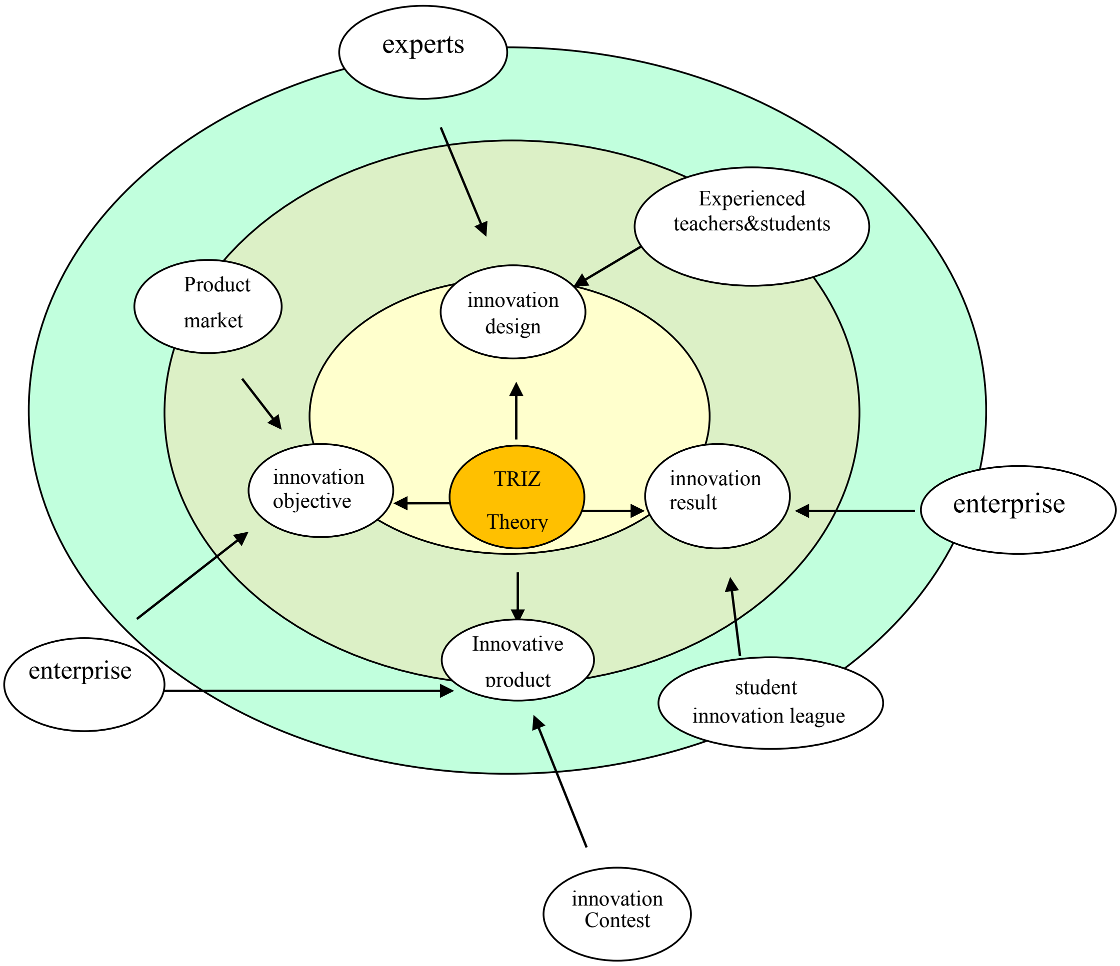


Fig 3. Innovation ecosystem

The system is divided into three levels: inner, middle and outer. The innermost layer is TRIZ theory, what provide an important role in the whole innovation chain. TRIZ theory is the starting point of College Students' innovation ability cultivation. Colleges is the main body of the middle, they should establish security mechanism, the key is in "Research". The main role of the outer is the enterprise and society, they need to cooperate with the college project. cooperate students, colleges and enterprises cooperate closely to build a collaborative innovation ecosystem".

5. Conclusions

In “Industry-University-Research” collaborative innovation mechanism, government is the lead, students are the main body, and schools play an important role. Collaborative innovation mechanism needs social enterprises actively participate, and make a concerted effort, to realize a positive interaction.

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DFMA AND TRIMMING. COMPARISON OF TWO SYSTEMATIC APPROACHES FOR SIMPLIFICATION OF DESIGN. FLOATING SQUIRING TOY - CASE STUDY.

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Abstract

The purpose of this document is the comparison of two powerful methods used for simplification of product design: DFMA (Design for Manufacturing and Assembly), and Trimming (TRIZ tool). Similar origins and identical targets of two methodologies raises the questions: Do they have any differences? How do they work?

To show how they are working on the real objects, author selected as a case study a product with simple design, Floating squiring toy. First, the design was simplified with DFMA approach. Then, the Trimming procedure was used for this purpose. The results and approaches were compared in the conclusions of this document.

Keywords: DFMA, Trimming, TRIZ, Case study, Elimination Analysis, Minimum Part Count, Functional Analysis, Functional Model, Patent Circumvention.

1. DFA - introduction

DFMA (Design for Manufacturing and Assembly) provides a systematic procedure for analysis of proposed design from the point of view of product assembly and manufacturing. This procedure results in simpler and more reliable products that are less expensive to assemble and manufacture. In addition, any reduction in the number of parts in an assembly produces a snowball effect on cost reduction: the drawings and specifications that are no longer needed, the vendors that are no longer needed, and the inventory that is eliminated. All these factors have an important effect on overheads, which, in many cases, form the largest portion of the total cost of the product [1].

DFMA tools also encourage dialogue between designers and manufacturing engineers, as well as any other individuals who play a part in determining the final product cost during the early stages of design. This means that teamwork is encouraged and the benefits of simultaneous or concurrent engineering can be achieved.

Design for assembly (DFA) should be considered at all stages of the design process, but especially during the early stages. As the design team conceptualizes alternative solutions, it should consider the ease of assembly of entire product or subassembly. The team should use a DFA tool to analyze effectively the ease of assembly of the products or subassemblies it designs. The design tool should provide quick results. It should be simple and easy to use. It should ensure consistency and completeness in evaluation of product assemblability. It should also eliminate subjective judgment from design assessment, allow free association of ideas, enable easy comparison of alternative designs, ensure that solutions are evaluated logically, identify problematic assembly areas, and suggest alternative approaches for simplifying the product structure – thereby reducing manufacturing and assembly cost.

The most important part of DFMA is stage called Elimination analysis. At that stage, the assembly sequence is analyzed according three basic factors: relative movement, ability to disassemble, and difference of materials. All interfaces should be examined. As a result, the components are classified as essential (needed) or not essential (theoretically not needed).

DFA basic considerations:

1. During the product operation, does the part move relative to all others already assembled parts? Only substantial motion should be considered. Small motions that could be accommodated, for example, by integral elastic elements, are not sufficient for a positive answer.
2. Should the part be separated from already assembled other parts in order to assembly or disassembly of the other separate parts?
3. Should the part be made a different material or be isolated from all other already assembled parts? Only fundamental reasons concerned with material properties are acceptable.

2. Trimming - introduction

Trimming is an analytical and problem-solving tool in TRIZ. It solves problem of design simplification by removing the components and reallocating their useful functions to the resources existing in the System and Supersystem [2]. In other words, trimming ensures that the functionality of the System is preserved by "teaching" other components of the System or its Supersystem to perform the Useful Functions of the trimmed components. The trimming method has two steps. The first step determines which components in the system should be trimmed; the second, which is also the key part, reveals the useful resources in the system and Supersystem capable of performing the useful functions of the system.

Once a component is selected for elimination, trimming offers multiple options. These options determine the problem statements and point at multiple possible solutions, from incremental to radical. The level of trimming determines the level of innovation: light trimming usually results in incremental improvements, while radical trimming leads to fundamentally new products.

Trimming a component should remove the disadvantages associated with that component. For example, removal of a high-cost component will reduce the total cost of the System. If the component generates a harmful interaction, it should be selected as a first candidate for Trimming. If the patent circumvention is our goal, we should focus on the claims. Then the components (functions, processes) mentioned there should become the candidates for Trimming.

However, removal of components usually results in new problems: how to make other components perform the useful functions of the trimmed component. These problems are called the Trimming Problems. Fortunately, the other TRIZ tools can help to address them.

3. Object of analysis

Author selected as a case study the patented product presented on the Figure 1. *Floating squir-ing toy.* US Patent No. 8,123,077 describes the water gun for kids usable during the heat of summer months. The water shooter is designed as a foam noodle. Usage is simple: Pull back the handle to load gun with water, take aim, and push the handle forward to shoot the water. The most important feature of this toy is ability to float on the water surface [3].

Fig. 1. Floating squiring toy - patent and appearance.

Fig. 2. Floating squiring toy components.

DFAM analysis of object

All components should be exanimated in the following way.

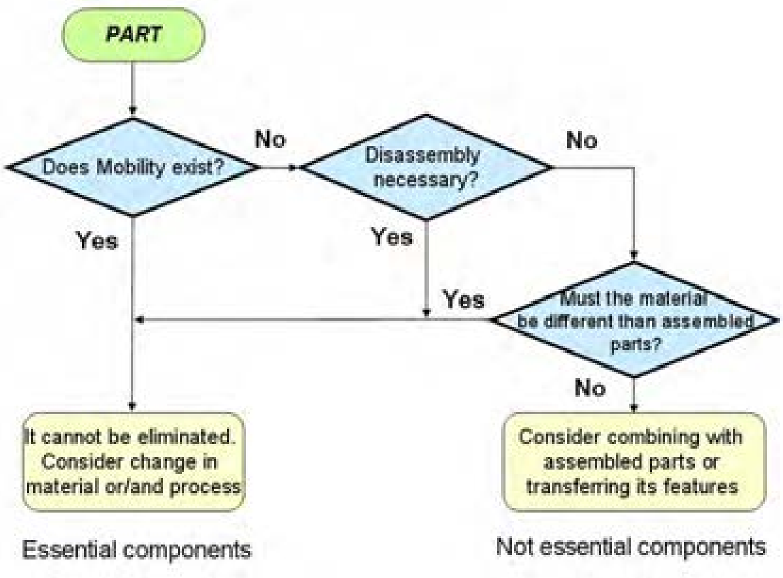
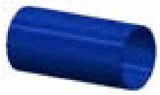


Fig. 3. DFA elimination analysis algorithm, based on three basic questions [1].

Table 1

Elimination analysis table.

No.	Name	Picture	Description
1.	PA shaft x1		Essential, because it is the first component. We need something to start assembly.
2.	PA piston x1		Not essential.
3.	O-ring x1		Essential from material point of view. Question 3.
4.	PA end plug x1		Not essential.
5.	PA long tube x1		Essential from material point of view. Question 3.

6.	PA bushing x2		Essential from assembly point of view. Question 2.
7.	PE long foam		Not essential.
8.	PA short tube x1		Not essential.
9.	PE short foam		Not essential.
10.	PA front plug x1		Not essential.

After elimination analysis we get the minimum number of parts: 4 instead 11 in the initial design. To achieve the desired number of components, the following ideas were developed in course of brainstorming:

- Combine front top with long tube.

Fig. 4. Idea of combining components.

- Combine PE foam with PA long tube.

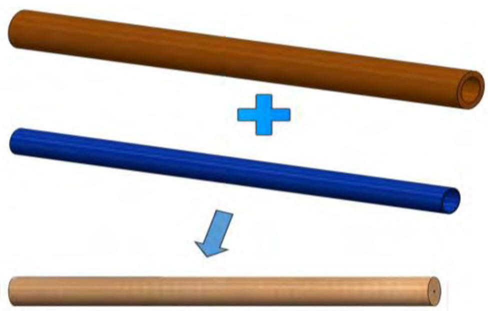


Fig. 5. Idea of combining the components.

- To satisfy floating requirements and guiding function, as a new material was selected: wood.

- Combine shaft with piston.

Fig. 6. Idea of combining the components.

- Create a handle with a shaft.

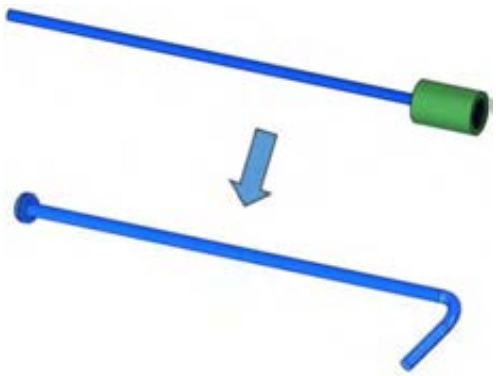


Fig. 7. Idea of combining the components.

The final design with reduction of number of parts from 11 to 4.

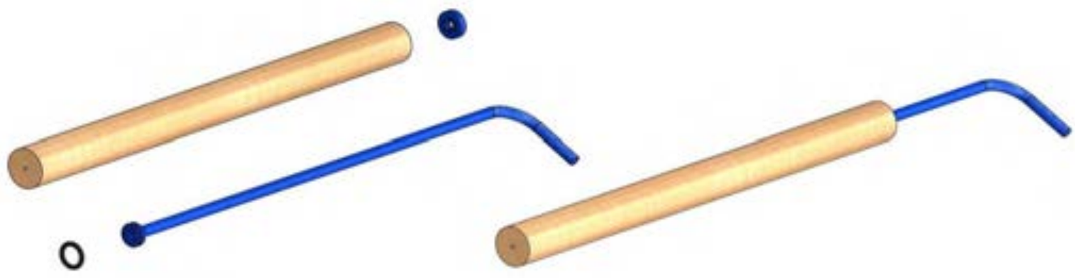


Fig. 8. Final design of Floating squiring toy after DFMA

1. Trimming of the object

First step is the analytical work: Interaction Matrix and Functional model.

Table 2

Interaction Matrix

	PA shaft	O-ring	PA piston	PA end plug	PA front plug	PA bushing1	PA bushing2	PA short tube	PA long tube	PA short foam	PA long foam	Water	Air
PA shaft			●	●		●	●						
O-ring			●						●			●	
PA piston	●	●			●	●						●	
PA end plug	●							●					
PA front plug			●						●			●	
PA bushing1	●		●				●		●				
PA bushing2	●					●		●					
PA short tube				●			●			●			
PA long tube		●			●	●					●	●	
PA short foam								●				●	●
PA long foam									●			●	●
Water		●	●		●				●	●	●		
Air										●	●		

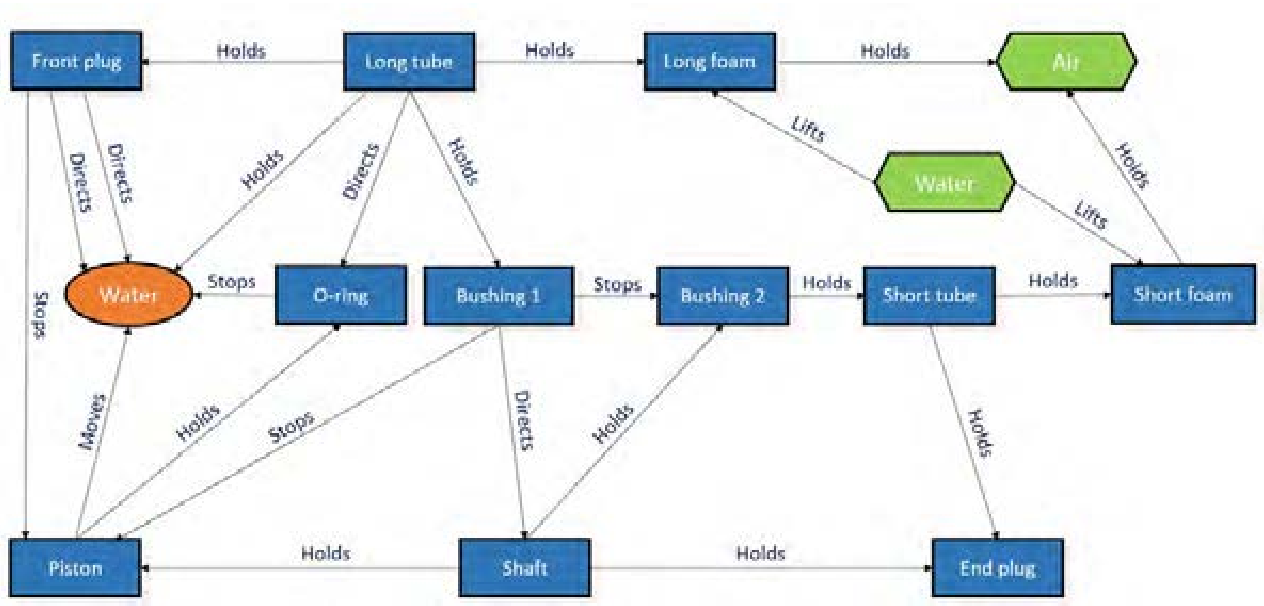


Fig. 9. Functional model of Floating squiring toy.

As a first component for Triming, Foams were selected. They are responsible for floating. Patent claims described this components as a key for floating of whole assembly. If this part will be trimmed, the patent could be circumvented.

Follow the Trimming rules (A, B and C) [2] resulted in the System described in Fig. 10. All functions were reallocated to other components that took the new responsibilities. New model describes the Scenario 1.

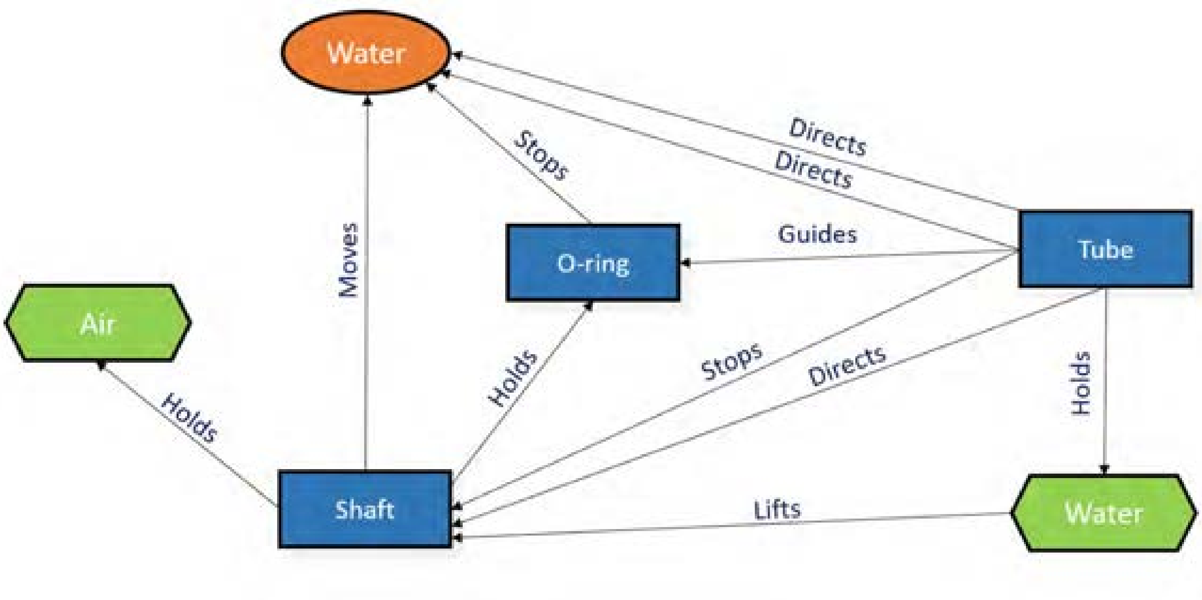


Fig. 10. Functional model of Floating squiring toy – Scenario 1.

Next, this functional model was converted into the specs for design. Several problems were resolved in order to preserve the needed functionality.

Fig. 11. Final design of Floating squiring toy after Trimming – Scenario 1.

The plastic *Shaft* has a hollow structure, and contains air inside. This air (Supersystem component) performs the floating function. *O-ring* is responsible for sealing, and *Tube* serves as housing for all components and reservoir for water.

For better comparison of DFA and Trimming, the second attempt was taken. This time, *Shaft* was selected as a first component for removing (from the initial Functional diagram, Fig. 9). During the Elimination analisys, this part was marked as essential. If we manage to remove it, that will be a significunt demonstration of Trimming as a more powerful tool. How to trim the part responsible for several functions? All these functions should be relocated to other components capable of taking the new responsibles. After a few a loops of trimming, we got the diagram below. New model – Scenario 2.

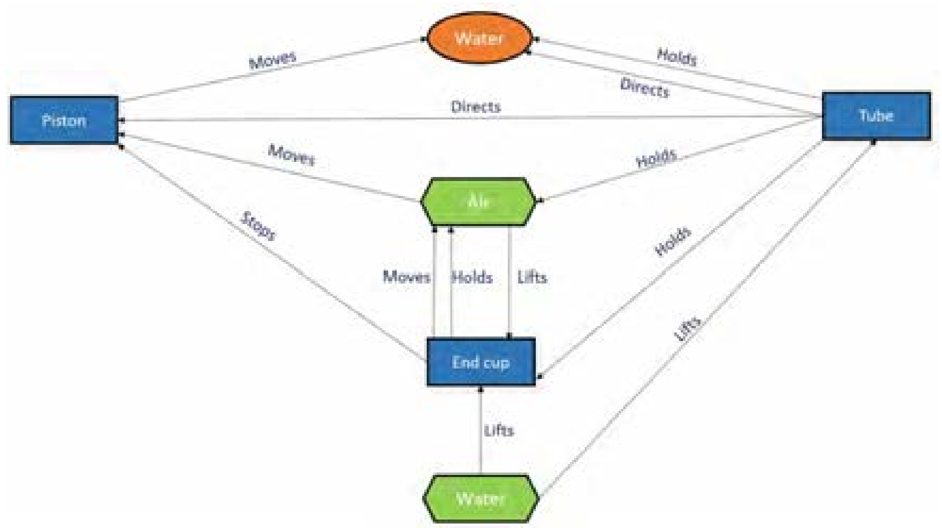


Fig. 12. Functional model of Floating squiring toy – Scenario 2.

This functional model was translated into 3D model concept. Several problems were resolved by brainstorming.

Fig. 13. Final design of Floating squiring toy after Trimming – Scenario 2.

The plastic *End cup* has a bellows structure, the air inside takes care of floating. Also, by compressing and decompressing the air inside it, user moves a piston. *O-ring* was removed, and its function was transferred to a *Piston*. *Tube* became a housing for all components and reservoir for water.

In third attempt, *Piston* was selected as a first component for Triming. This component is responsible for moving the water, and exists in the previous design. It is challenging to remove it, but let's try. After trimming of this component, all its functions should be relocated to other components capable of taking the new responsibilities. After a few a loops of trimming, we got the diagram shown below. New model – Scenario 3.

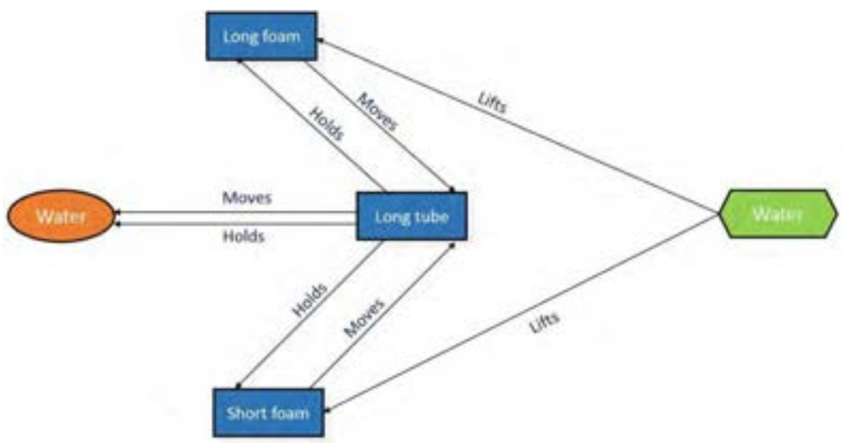


Fig. 14. Functional model of Floating squiring toy – Scenario 3.

This model was used as an input to create an alternative solution. As usually, the secondary problems appeared. For example, How the long tube itself could moves water?

Fig. 15. Final design of Floating squiring toy after Trimming – Scenario 3

The plastic *Long tube* was redesigned into bellows shape. Its volume changes by compressing and decompressing. *Long foam* and *Short foam* were redesigned into wooden rigid elements able to compress the bellow. They also deliver the floating function.

In TRIZ terms, as systems evolve towards their Ideal Final Result, the number of parts per useful function delivered tends to reduce. Any DFMA or Trimming activity that begins to run out of steam at ratios significantly higher than this value are suggesting the need for a shift to a new paradigm. Various TRIZ tools help identifying such paradigm shift.

In terms of benefits to Trimming, DFMA offers two main opportunities. The first relates to the use of information that enables engineers (and probably more importantly, their managers) to quantify the benefits of applying DFMA techniques. The second, technically more important, reason relates to the potential benefits of incorporating the knowledge of DFMA best practices into the TRIZ framework [4].

Conclusions

All tools have advantages and disadvantages. DFMA is good for analyzing the complex Systems (50 pieces and more) in relatively short time. Trimming can work with max. 20 pieces. From the other side, DFMA, after elimination analysis, creates a psychological barrier. What does it mean “essential component”? – Component that is needed, so the designer shouldn’t even think of removing it, and skips to the next item. In case when designer uses Trimming, the limit of trimming depth is in his mind.

Both DFMA and Trimming tools are very valuable for cost cutting, simplification, optimization of design and patent circumvention. The output from DFMA gives us understanding how many pieces we need to deliver exactly this same function as the system-at-hand. In a short time, we were able to deliver a new design with 64% less of components, preserving the same common look and feel. It would be advisable to use this tool at the early stages of new product development and design improvement stage.

From Trimming, we got three different solutions consisting of only 3 pieces each. In these cases, we reduced number of components by 73%. To preserve the main function, all of them differ from each other. Trimming looks as a perfect tool for patent circumvention and new product development. From that point of view, this tool looks better than DFA.

The main advantage of Trimming which directly impacts the number of parts is use of resources, both from inside and from outside of technical system. The more resources we use, the more chances we have to use them for free. Usually, air, gravity, atmospheric pressure, water in swimming pool are for free. Another benefit is not blocking the thinking: any component can be trimmed. Of course, any project has some boundaries, limits, sometimes hidden needs of costumer, and they should be localized to satisfy the customers’ expectations, but even in this case new design ideas can be discovered during analysis by using other TRIZ tools.

Both tools can give a valuable savings, when design team are properly using them. Reduction of number of components provides for savings from manufacturing and assembly time, increasing reliability or reducing the risk. From this point of view, DFMA and Trimming are two sides of the same coin.

Author could suggest for a future research development of a new approach for sequential use of two tools: first DFMA, then Trimming. The benefit from such analysis can be considered in a few aspects. First, if the System is big, it is easier to perform DFA than Trimming. Second, the new design can be tested from point of view of its resistance to patent circumvention. If we cannot simplify it by Trimming, it means that our solution is strong from that perspective. If we can do, that will be the next iteration of simplification. That approach can move us far beyond the System. Another potential benefit can be refining of new design. DFMA has additional steps to consider small features related to handling, inserting and manufacturing issues. All those findings can bring a new product that is cheaper, better and faster manufactured.

Use of these tools depend on human thinking. After using one tool, we believe that the achieved result represents the limit. When we use another tool, the perspective changes, new resources appear, new physical effects can be used, and the new limits can be achieved.

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ENHANCING STATISTICAL DESIGN OF EXPERIMENTS WI TH TRIZ AND VICE - VERSA

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Abstract

The generic new product development cycle, follows the path of identifying a need-developing concepts-designingdesigning- testing- refining- implementation. Modern TRIZ has developed many tools for identifying needs and later converting them into concepts by usage of various tools. Once the conceptual development is completed we begin the phase of designing the prototype. Often in the journey of design, one of the tools that are used is statistical design of experiments.

The most important aspect of the statistical design of experiments is the initial planning phase wherein teams brainstorm numerous factors and their levels that they wish to test in the design so that they can arrive at an optimal design. However, this approach can often lead to identifying, many factors forcing designers to choose highly saturated fractional factorial designs which can identify impacts of only the main factors thus losing out on vital piece of information associated with interactions or increase the number of experiments to be conducted due to more factors being tested

By utilizing the law of system completeness of TRIZ, designers can identify the main factors easily reducing the experiment effort. During analysis of the experiment, designers often have a key task of optimizing more than two output variables, and many times designers try to achieve an optimal. This approach can be drastically modified where based on the outputs and the critical factor we can identify contradictions and resolve them to achieve win-win solutions. Similarly, many times during projects wherein cause-and-effect chain is built to identify key problems one of the main considerations is the fact that only validated causes are used for the formation of the key disadvantages. Statistical design of experiments can be a very effective tool in helping understand causative factors to have a more Robust cause-and-effect chain. This paper will discuss both the applications with case studies.

Keywords: Statistical Design of Experiments, Law of System completeness, Cause and effect chains

1. Overview of Statistical Design of experiments

1.1. Brief overview[i]

Design of Experiments is the branch of applied statistics deals with planning, conducting, analysing and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

A strategically planned and executed experiment may provide a great deal of information about the effect on a response variable due to one or more factors. Many experiments involve holding certain factors constant and altering the levels of another variable. This One-Factor-at-a-

Time (or OFAT) approach to process knowledge is, however, inefficient when compared with changing factor levels simultaneously.

Many of the current statistical approaches to designed experiments originate from the work of R.A. Fisher in the early part of the 20th century. Fisher demonstrated how taking the time to seriously consider the design and execution of an experiment before trying it helped avoid frequently encountered problems in analysis. Key concepts in creating a designed experiment include blocking, randomization and replication.

A well-performed experiment may provide answers to questions such as:

- What are the key factors in a process?
- At what settings would the process deliver acceptable performance?
- What are the key, main and interaction effects in the process?
- What settings would bring about less variation in the output?

A repetitive approach to gaining knowledge is encouraged, typically involving these consecutive steps:

1. A screening design which narrows the field of variables under assessment.
2. A "full factorial" of design which studies the response of every combination of factors and factor levels, and an attempt to zone in on a region of values where the process is close to optimization.
3. A response surface design to model the response."

In summary, Statistical Design of Experiments enables a researcher to convert a process or product design to a statistical model that is based on cause and effects

1.2. General process followed

1. The general steps followed in conducting the statistical design of experiment are as follows
2. Before you begin the experimental setup, it is important to understand the objective of the experiment and identify what are the important outputs that we intend to measure.
3. Thorough process understanding/product understanding is important as the experimenter then decides all the possible variables that he intends to use as variables to study the impact on the output. To achieve better consistency in identification of variables, process flowchart, inputs or outputs of processes, and brainstorming is utilised in identification of the experimental variables
4. Based on the number of variables identified in step two the experimenter chooses an appropriate experimental plan. If the number of variables identified are far too many than the allocated cost or time for the experiment, the experimenter rationalises the variables and chooses an appropriate experimental plan. experimenter plans can be broadly classified as screening experiments and experiments conducted for optimisation
5. Experiments are conducted as planned and all the identified outputs are measured
6. Statistical analysis of the experiment is conducted to determine the transfer equation that governs the system
7. Confirmation analysis is conducted to confirm the replication ability of the transfer equation

1.3. Key challenges in the steps

1. Before you begin the experimental setup is important to understand the objective of the experiment and identify what are the important outputs that we intend to measure.

(Challenge: Identification of what to measure, as choice of wrong output can result in not meeting the identified objectives)

2. Thorough process understanding/product understanding is important as the experimenter then decides all the possible variables that he intends to use as variables to study the impact on the output. To achieve better consistency in identification of variables, process flowchart, inputs or outputs of processes, and brainstorming is utilised in identification of the experimental variables.

(Challenge: This approach identifies far too many variables being identified thus leading to choose an experimental design that is screening nature instead of optimisation, that is often resolved by sequential nature of experimentation however this approach can be very time consuming and expensive.)

3. statistical analysis of the experiment is conducted to determine the transfer equation that governs the system.

(Challenge: Statistical analysis identifies various interactions however does not try to eliminate them. Also, when dealing with multiple outputs being modelled it forces us to choose an optimal setting for a variable that will meet both the outputs)

All the above challenges in statistical Design of experiments can be easily overcome by using multiple TRIZ tools and concepts, namely, TRIZ law of system completeness, law of Energy conductivity, contradiction resolving, cause and effect chains, operating zone and time & resources

2. TRIZ Background:

TRIZ (Theory of Inventive problem solving) is a science that is derived from study of patents with a primary objective to eliminate random trial and error in the journey of developing inventive solutions. TRIZ research lead to a primary conclusion that evolution of technological systems is not random but it is governed by a set of objective laws. Knowledge of TRIZ enables a researcher or inventor to systematically overcome contradictions by use of available resources thus resulting in breakthrough solutions.

3. How TRIZ tools can overcome the identified weaknesses

3.1. Law of system completeness

The Law of System Completeness: Every technical system consists of four components: engine, transmission, control unit and working unit. Synthesis of technical system requires all these components and their minimal capability to perform system functions. If any component is missing, the technical system does not exist, if any component fails, the system does not "surviveiithis law is depicted in Diagram 1 with the dotted lines identifying the four essential components

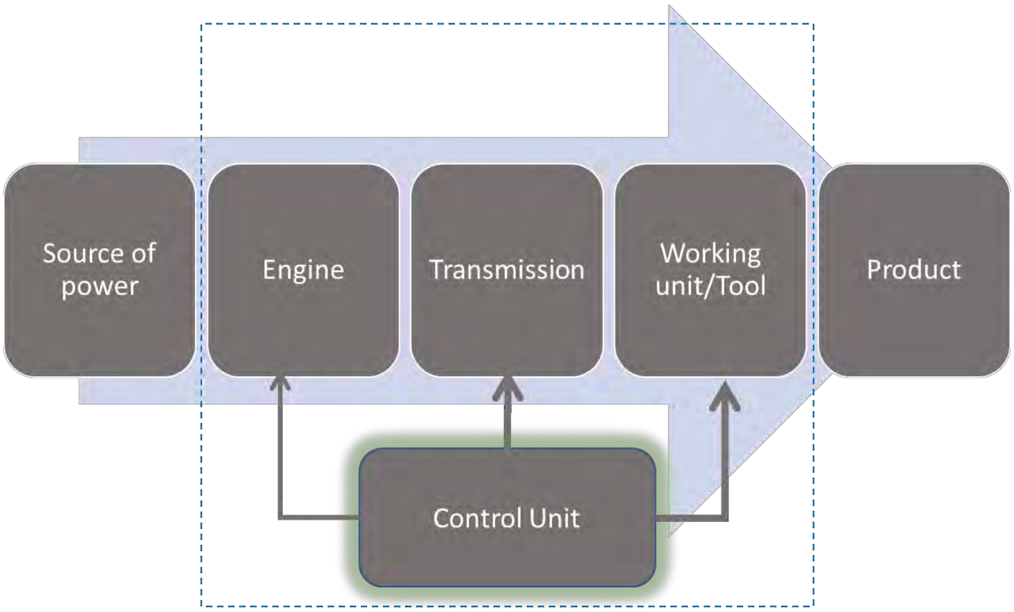

Fig 1. Law of System completeness

Corollary to the Law of System Completeness: to make a technical system controllable, at least one of its components should be controllable. Such system is capable of changing properties in the way required by the operator.iii

This law can be effectively utilised for the identification of the key components and the variables of control that can have a direct impact on the end functionality. As this law describes the minimum set of components necessary to deliver the functionality it helps us in identifying scientifically, variables that can have a direct impact on the functionality effectively. To understand the application of this law lets consider the standard experiment that is used often in the education of design of experiments using a catapult. The diagram2. Below is a standard catapult that is utilised for learning design of experiments.

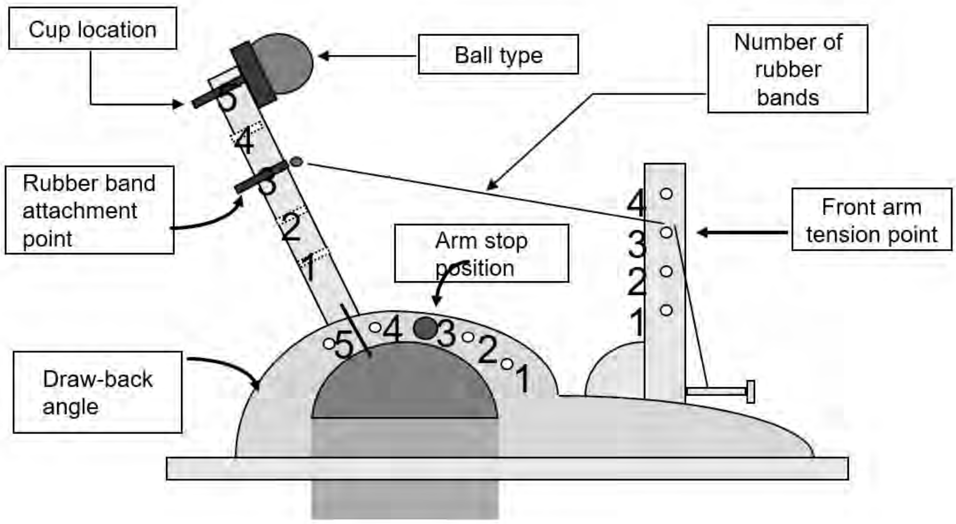

Fig. 2 catapult design

The objectives of the experiment are defined as meeting the target shot of an X distance within certain limits.

On application of the method for identification of parts based on the Law of System completeness

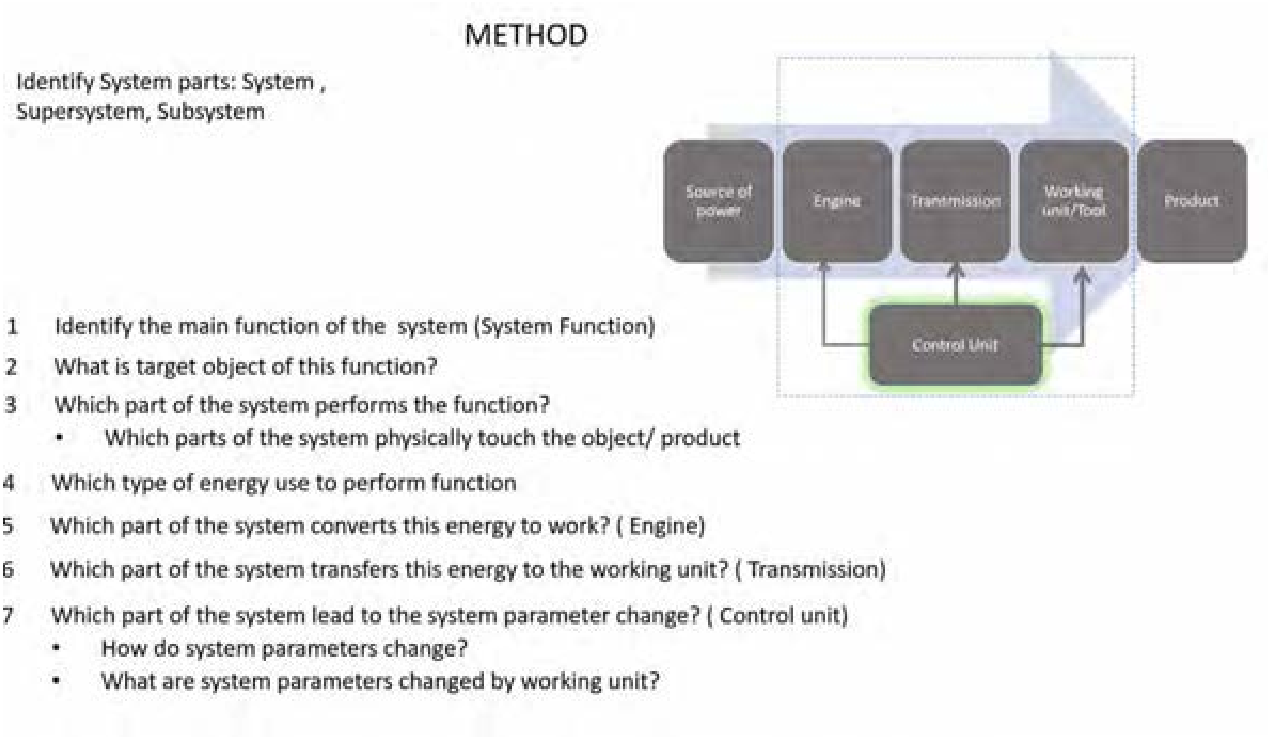

Fig 3. Application method of law of system completeness

Answers

1. The main function of the system is to hit the target specified
2. The target object is the target specified
3. The ball
4. Kinetic energy
5. The Kinetic energy as imparted at the release of the Catapult
6. The air, wind, gravity

On reviewing the above identified key parts, we control the weight of the ball, the angle of release of ball, the Kinetic energy imparted to the ball the air, wind is non-controllable, gravity is a constant.

Immediately on rationalising the same we can see that if the weights of the balls to be used are not very different, we can choose to omit them from the experiment, to maximise the distance the angle of the projectile must be 45 degrees, thus the main variables that need to be considered in the experiment are the ones associated with imparting the Kinetic energy to the ball. Moreover, kinetic energy is a function of the square of the velocity thus indicating that the system will be more sensitive to factors associated with velocity and not weight of the ball.

Once the control factor is identified as the Kinetic energy imparted to the ball the law of system completeness can be again reapplied with the main function being to move the ball. Answering the questions as detailed in Fig. 3 lead to

1. The main function is to move the ball
2. The object is the ball
3. The working unit is the cup
4. Kinetic energy
5. The kinetic energy of the arm on which the cup is mounted
6. The arm stop position is the transmission.

On reviewing the above, it is easy to now see the key variable as drawback angle, front arm tension point, and the arm stop position as they will primarily govern the Kinetic energy imparted to the cup. Once these variables have been identified we can plan an experiment accordingly as described earlier with the main advantage being that we have been successful in identifying key variables for the experiment efficiently.

3.2 Law of Energy conductivity

The law of energy conductivity: prerequisite to viability of a system is the free flow of energy through all system parts.

Corollary to the law: to make a part of the system controllable it is necessary to provide power conductivity between given part and the control unit.[iv]

Every technical system is a conductor and converter of energy. If energy does not pass freely through the entire system, a certain part of it will stay without energy and will not operate. The energy originating from outside or generated by the engine is spent on maintaining the performance of the technical system (all its parts. Thus, it is desirable that technical system should not only be a suitable energy conductor but should also operate with minimal energy losses (such as losses incurred by transformation, production of useless wastes, etc.).

This law can be extrapolated also to the energy transfer that occurs between the working unit and the product, as if this energy transfer is perfect, in other words 100 percent efficient the achievement of the function to be obtained will be 100% else there will be harmful effects that will be visible in the form of defects, or other energy outputs like noise, heat etc. This law can be very effective in overcoming the challenges associated with what to measure as an output. Rather than measuring conventional outputs if the focus of the experiment is diverted to measuring this function of energy transfer and if this function of energy transfer is improved we will obtain far better results of control in the products or processes that we are improving.

To understand this, author will cite a case study where this law was utilized effectively to improve processes.

In the process of groove grinding of a bearing steel job, the problem under consideration was size variations that occurred in the job during grinding resulting in defects as scrap. Traditionally the factors would be brainstormed and the primary measurement that was undertaken was the obtained size of the job. Post experimental confirmation while the size variations would improve many times there were variations with surface finish obtained and we were not able to achieve both size and surface finish simultaneously. Also, the obtained results would not last for a long time resulting in frequent attempts to optimize. When this law was applied to the problem, the primary function identified was material removal. This material removal is achieved by the kinetic energy of the grinding wheel and the job at the interface created by feeds and rotation. Kinetic energy is primarily a function of angular and linear velocity in this case which is then a function of time see diagram 4,

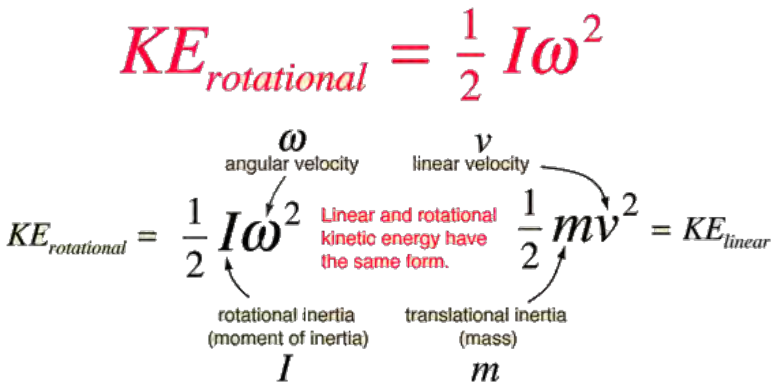

Fig. 4

And thus, it was decided to conduct an experiment wherein the outcome decided to be measured was the function between theoretical time of the grinding as per the cycle and the actual time taken to achieve the size. Ideally Theoretical cycle time= Actual cycle time. The results obtained using this procedure surprised all as not only did we achieve the size but also the surface finish was obtained. Studies were later conducted to compare the energy consumption of the machine and it was proven that the optimization achieved by utilizing the law of energy conductivity as resulted in power savings and reduced maintenance of the machines because of better energy utilization achieved.

3.3 Contradiction resolving

Often during the process of experimentation, the designer is attempting to optimize more than one Main parameter of output and lands in a situation wherein control parameters need to be at an identified value to achieve the result for one output and the control parameter must take an opposite value to achieve the results for the second output parameter. See diagram below

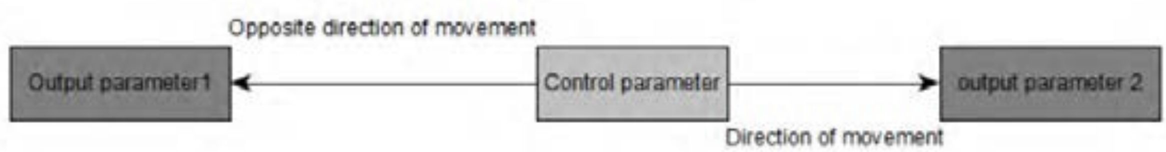

Fig. 5 Scheme of optimization

This diagram clearly represents a physical contradiction that exists in the system and TRIZ tools for resolving physical contradiction can be easily used to find an elegant solution to the problem.

To illustrate the above in a project associated with development of a product for separation of liquid droplets from gas, one of the conditions in the experiment were that the inlet and outlet diameter must have a small size of X value to achieve high separation of the liquid droplets and must have a large size to not create back pressure in the system that could lead to leaks in the separation system design. The traditional approach often taken is that of optimizing the value however by using the physical contradiction resolving method we could achieve both the objectives very easily.

3.4 Cause and effect chains operating zone time & resources

Often during analysis of experiments one encounters interactions. Interactions in analysis of design of experiments occur when the effect of one factor depends on the level of another factor. You can use an interaction plot to visualize possible interactions.

Parallel lines in an interaction plot indicate no interaction. The greater the difference in slope between the lines, the higher the degree of interaction. Once interactions are found to be statistically significant the experimenter uses the interaction graph to set the variable at the values as recommended by the graphs to obtain the desired results. For example, in the catapult experiment an interaction can be found in the drawback angle and the arm stop position as depicted in the diagram below

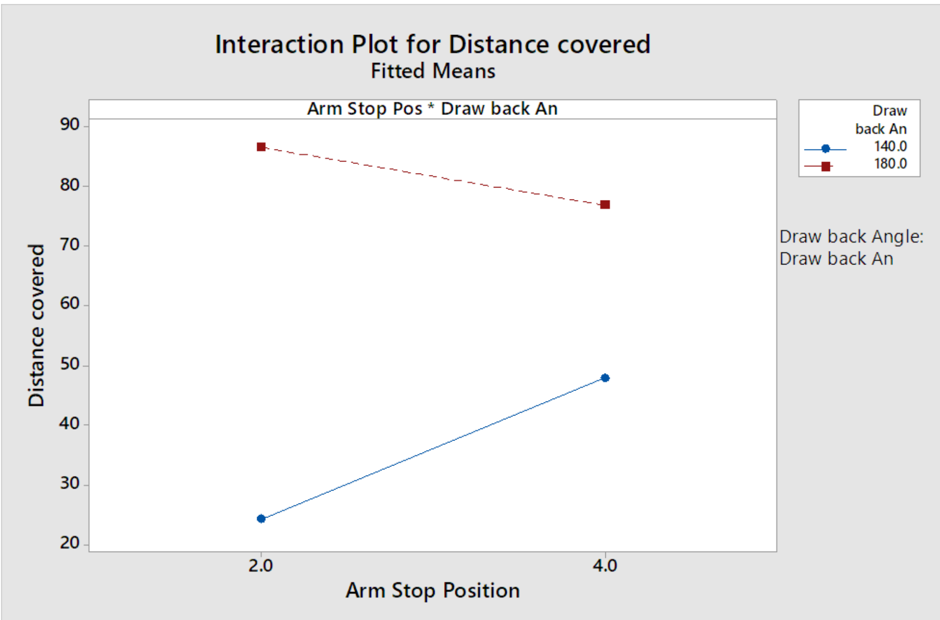

Fig. 6 interaction graph

This graph clearly indicates that the average distance you achieve while being a function of the draw angle is also co-dependent on the value of the stop pin.

Rather than just setting the values to achieve the results, it is important to understand that experiments are the best way to understand and validate the cause and effect chains that exist in systems and quantify these relations mathematically. Once it is established that the kinetic energy imparted to the ball is the end outcome, using TRIZ concepts of operating zone and operating time, it is evident that this energy imparted to the ball is primarily at the interface of the arm and the ball. The potential energy imparted to the cup location through the arm is converted to the Kinetic energy imparted to the ball at the release point. The resource that negatively impacts the transfer of potential energy of cup to Kinetic energy of ball is gravity. This now helps us understand that when the drawback angle is low and the arm stop position is at 2 we have a longer travel and we get shorter distance, indicating that there are higher losses associated with gravity, thus implying that there is a threshold value that potential energy must be greater than to overcome the losses due to gravity during the energy transfer. Such understanding during development is extremely critical in experimental analysis

TRIZ advocates that during the preparation of the cause and effect chains it is necessary to have only validated causes in the chain, in case there are any assumptive causes TRIZ recommends identification of these in the chain however, in many practical situations such understanding is often not clear and even experts do not have clear answers. In all such situations, a statistical experiment that is conducted and analysed using methods discussed above will help in building robust cause and effect chains and thus identifying the key problems to solve more efficiently.

4. Conclusions

The author has described all the gaps associated with designing statistical experiments and proposed TRIZ methods to overcome these gaps and how statistical design of experiments can strengthen cause and effect chains in TRIZ

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EVOLUTION MAP BASED ON ADVANCE INVENTION, PROCESS AND CASE STUDIES

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Abstract

While the boundary between industries has become blurred and changed faster, the patent has become more significant day by day. It is crucial for a company to proactively explore the industry's future in advance before the existing and potential competitors recognize and dominate it. Unfortunately, the engineers are able to compose patents within their knowledge boundary because of insufficient knowledge of other industry as well as lack of understanding customers' desire of other field. The usual engineers are lack of both of innovation knowledge. Even if the engineers have enough knowledge of the needs of the customers, such needs reflects just current point of view. Customer survey shows basically passive/reactive opinion of existing technology or product, which is far from pro-active long-term evolution. If a company launches a new business of unchallenged direction, it is urgently required to identify the past and present of the industry and to predict future image and generate patents for 3-5 years after.

Based on the TRIZ evolution theory and the evolution map, Samsung Electronics TRIZ team has designed a practical application of evolution theory and tried to create patents for them. This article introduces the evolution map based in advance invention of Samsung TRIZ team and the field application cases of home robot invention. The whole process is as following. Firstly, patents were collected as many as possible from the major players in a specific industrial field and classified based on similarity of them. Secondly, the participants who classified the patents have extracted the evolution theme and evolution drivers through internal workshop. Evolution theme is the hypothesis of the ultimate goal of the evolution, and evolution driver is the hypothesis of the direction and path of the actual system change toward the evolution theme. If a couple of patents' are discovered during classification process to support the hypothesis, the hypothesis is accepted and visualized as a map so called evolution map. An evolution map is composed of an evolutionary theme and an evolution driver with support patents information in a tree or matrix form. Along the evolution driver axis, the current location can be pin-pointed and the next stage of the evolution driver becomes a next patent theme of the future. Combining evolution theme and context, new patents could be drafted in advance. The patents derived from this process are pending in Korean, US, World patent office. The result of this technique proved to Samsung Electronics that TRIZ is able to predict future image and compose future patents systematically as well as to solve existing problem of current industry.

Keywords: technology evolution; in advance invention; patent evolution map; EMS (evolution map system); TEOM (technology evolution opportunity mining)

1. Introduction

1.1. Motivation

As IT industry development has been accelerated since 2000 year by year, predicting future divided literally life and death of a company. The boundaries between industries have been blurred, which makes future prediction harder and more complex. It is inevitable to change its business DNA to survive, which means future prediction tools should 'read' as well as 'lead' 'inter-species' evolution across the traditional business boundary. One more requirement for future predicting tool is seamless link to technical solution as well as intellectual property aligned with customer's desire and needs. The authors hypothesized that TRIZ's evolution theory could provide a working frame reading evolution path, estimating future trajectory, creating new intellectual properties.

1.2.Scope and Objective

Many people want to figure out the future technology. If we investigate the systems with intrinsically same feature in the past, we might estimate how our systems would be likely to change in the future. “Evolution trends of technology” [1] could accelerate this process. After studying 8 trends defined by Altshuller [1], and more detailed versions by other TRIZ researchers [2], Samsung Electronics has also standardized 30 evolution patterns inside I-Spark(Samsung Electronics’ own TRIZ software, Figure 1, and applied them for prediction as well as problem solving since 2008 [3].

Fig. 1. Samsung's 30 evolution patterns in I-Spark

Applying the evolution patterns to the technical information such as patents, it is possible to draw a figure that looks like a phylogeny tree of biological evolution, so called evolution tree [4] or TEOM (technology evolution opportunity mining) matrix [5].

2. Results and Discussion

2.1. Approach

The focus of this research is divided into two fields, firstly, how to interpret patent information effectively and efficiently, and secondly, how to ensure creating future patent concepts which reflects ‘real needs’ of future customers. In order to deliver evolution map from massive number of patents, the authors developed a working infra so called EMS (evolution map system, Figure 2), a human-computer interface to analyze patents and draw an evolution map in 2014.

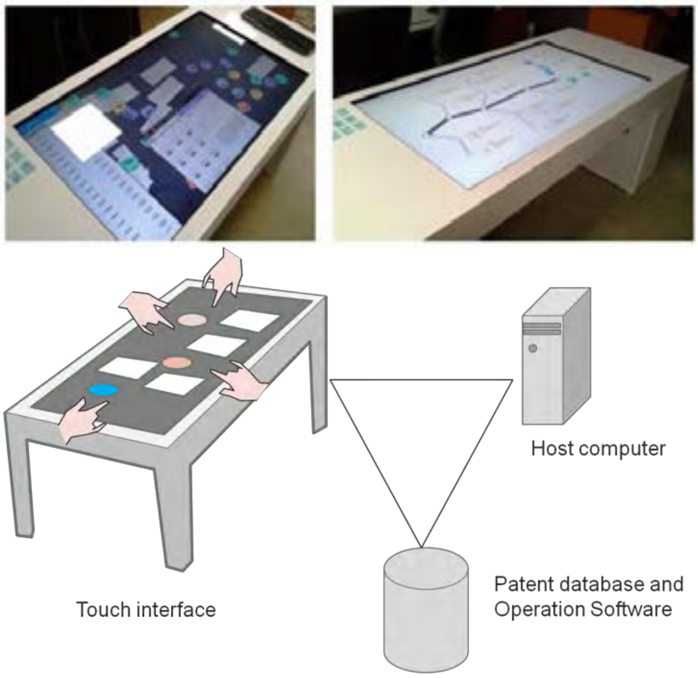
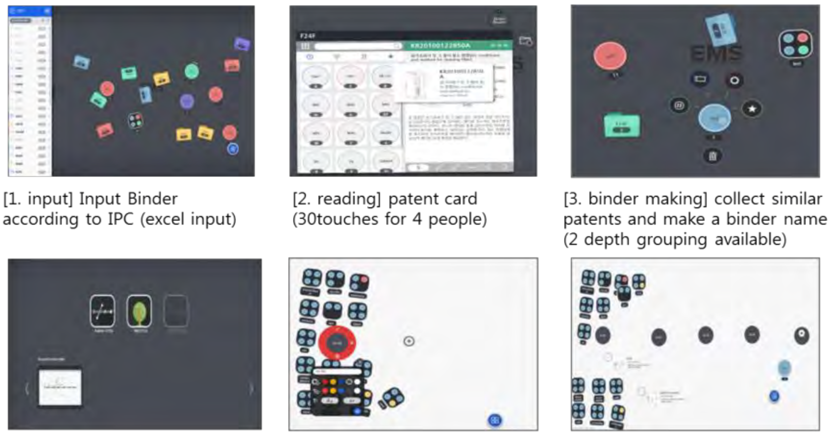


Fig. 2. Multi-touch patent analysis and layout interface EMS (Evolution Map System)

The input of EMS is a large number of patents in excel format and the outcome is a patent database set with a classification structure and an evolution map in which an evolution hypothesis and steps of evolution are visualized. EMS is composed of 2 sub-modules: the first for classifying patent information and the second for lay outing an evolution map based on classified information. The first module, patent clustering module, can take up to 10,000 pieces of patent information and visualize data on the screen (titles, applicants, filing dates, representative drawings, abstract, independent claims) as A4 size virtual card format denoted in the following Figure3.2. The physical dimension of EMS is 60 inch display with usual working table height. On the top of the table display, multi touch interface up to 30 touches has been installed which enables 4 people to handle the virtual patents cards at the same time on the same display.

After reading the information written on the “patent card”, the analyst collected similar patents together using multi touch interface into a same "binder". At this time, in relation to the similarity of patents, proper name of the binder was defined by the analyst team. To ensure the reliability of the patent classification system, analysts make in depth communication during clustering the cards. Up to now EMS can provide two levels of bottom-up clustering. In deriving the hypothesis of evolution, the authors referred Samsung’s 30 evolution patterns [3] as well as Altshuller's classical evolution trends [1] as a highest priority. It is impossible to discover the similar trend which can explain real patents collection; the authors defined our own evolution hypothesis based on the ideality axiom of the classical evolution trend.

Evolution hypothesis could be induced by the discussion of multiple analysts at the same place, which would be used to visualize the evolution map. After clustering the cards and summarizing evolution storytelling, the analysts move to mapping module, where they connect the classified information to storyline to complete the hypothesis map of the evolution. Evolution hypothesis maps can be shaped as tree type or matrix type map so called TEOM [5]. Current EMS v.1.0 supports tree type layout (1.x dimension) only. In 2017, matrix type evolution map (over 2 dimensions) i.e. TEOM also has been systemized as independent software which can be used aligned with EMS.



[1. input] Input Binder according to IPC (excel input)

[2. reading] patent card (30touches for 4 people)

[3. binder making] collect similar patents and make a binder name (2 depth grouping available)

[4. move to map] Toward mapping module after whole binder making

[5. evolution hypothesis storytelling] Draw evolution hypothesis frame

[6. Patent mapping] Attach patent binder onto the evolution hypothesis frame

Fig. 3. Working Process with EMS

In order to discover tangible patent items in the near future, the buyers utility map technique [6] from blue ocean strategy, persona, customer journey map [7] from service design were employed to compensated the weak part of TRIZ evolution theory. Buyer's utility map and customer journey map helped the authors to discover unmet needs of the customers. The authors could create new system schema to meet the discovered needs of the customers. When the new concept derived, the ideas was converted to the search keyword for the prior art search to verify the real new-ness of the concept in real time. After such preliminary prior art search, discloser of invention was drafted based on the literally 'new' concept. Table 1 summarizes whole procedure of evolution map based in advance invention.

Table 1

Evolution Map Based in Advance Invention Full Process

process	description	input	outcome
1. Define	Define scope and purpose, acquire raw data	Search Keyword	Raw patent/journal information
2. Investigate	Classify raw data, extracting multi-layer evolution hypothesis	Raw patent/journal information	Classified information, evolution hypothesis

3. Visualize	Layout evolution hypothesis with evidence patents	Classified information, evolution hypothesis	Evolution Map(tree type or matrix type), Future evolution direction
4. Evolve	Suggest new ideas aligned on the future evolution direction	Evolution Map, Customer context, Seed Patents	Promising ideas
5. Realize	Verify new-ness by real-time prior art search, verify feasibly	Promising ideas	Prototype, simulation, DOI, Plan for realization

2.2. Case 1. Smart Home

In 2014, in order to set up the smart home strategy, the authors were asked to analyse more than 6,600 patents (US patent only) to see the smart home's evolution direction as well as to suggest new concepts of the *novel* patent direction. The collected 6,600 pieces of patents information were loaded up to EMS. 7 analysts (one of them was TRIZ evolution specialist, others were domain experts - mechanics, acoustics, firmware, sensor, UX design, and visual design) classified the big mass of the information into 701 binders under 23 upper groups by bottom-up grouping in 10 working days. The analysts team could induce evolution hypotheses with intensive verbal communication during the binding work. Not only had a simple data clustering function, but also EMS provided a verbal communication environment to unveil the technology evolution and new perspectives of the future shown in the Figure 4.

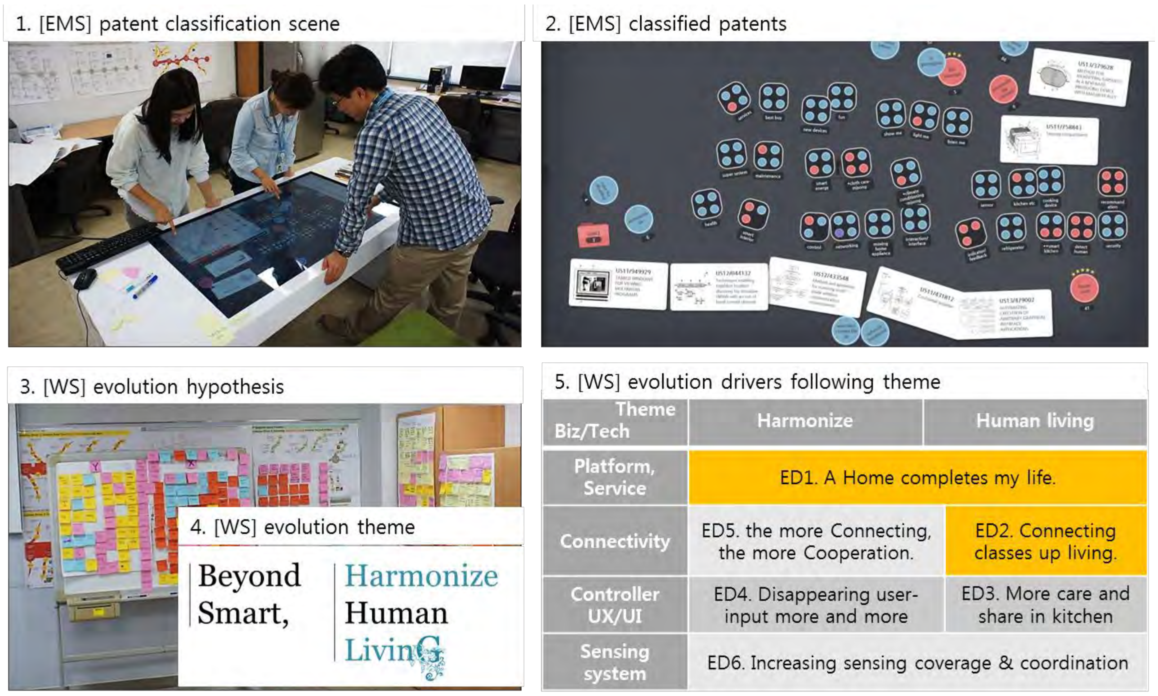


Fig. 4. Smart Home patent evolution map – classification and hypothesis making

Figure 5 presents a map based on the evolution hypothesis "Home completes my life" with 7 evolution steps. The first step starts from a home appliance with basic function only, the second step provides a convenient function, such as remote control, timer, the third step provides functions that makes me free from some risks that might occur. Current home appliances are located on somewhere between the 2nd or 3rd step. The 4th step is accompanied by the connectivity provided by some smart home start-ups, for example Nest Lab. 5th step provides a chance to create and share something through connectivity in the previous step. At the 6th step, smart home system might touch and organize human's emotion beyond just understanding human being. The final 7th step might create absolutely new experience without any system, which corresponds to the definition of ideal system of TRIZ theory [1].

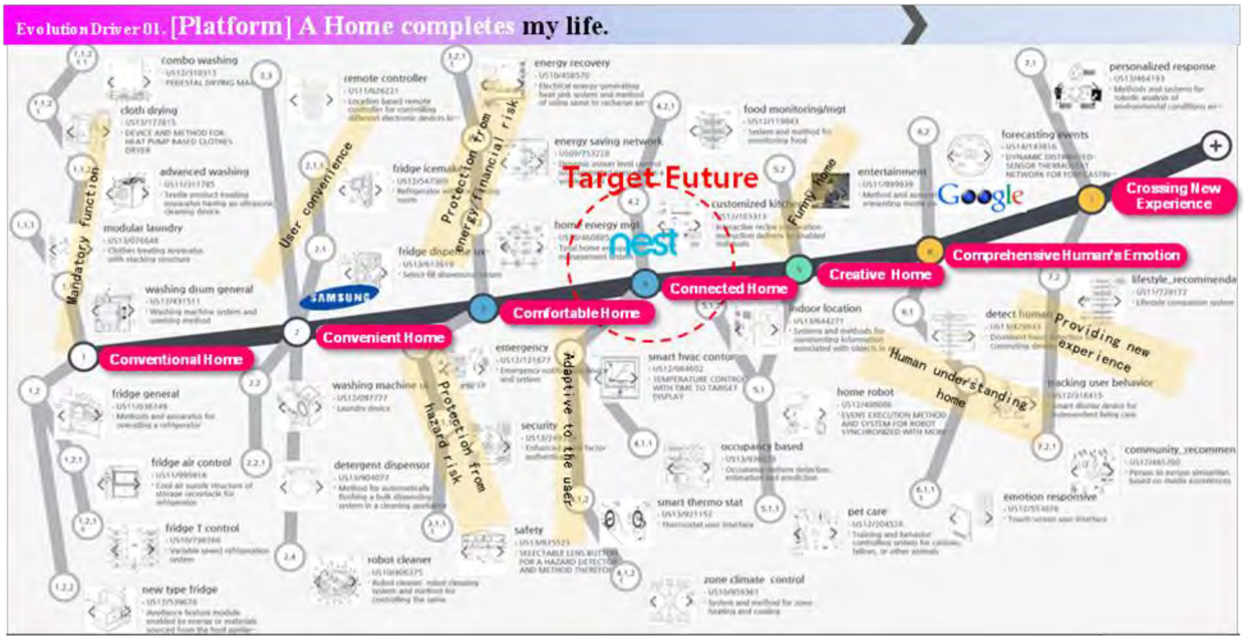


Fig. 5. Smart Home Evolution Map- Home completes my life

When the authors investigated carefully this evolution map, current status of Samsung was estimated around step 2 and step 3. The goal for near future was the 4th or 5th step where connecting things could deliver uncovered experiences. The authors asked ourselves what else devices could be connected to the conventional home appliances in the near future. The candidates of new connectivity were as following: family members out of home, family members who are not housewife, infants or handicapped or aged persons, companion animals and plant, home robot and so on. The authors have chosen the issue, 'what' would connect to the smart home around step 4-5 of the evolution map in Figure 5. One of answer that Samsung had never covered was home robot.

There was some evidence a couple of competing company such as Google had great interest in home robot. Google's 2 patents, USP 8380349[8] and USP 8307061[9] were well matched the 4~5 th steps (the next stage of the current evolution step) of the hypothetical evolution map. USP 8380349 makes it easy for Google to dominate robot cloud and search engine as a technology to provide its contents to robot to find a way to manipulate objects using the information stored in the robot cloud. The other patent, USP 8307061 claims the way how the home robot ask query to the robot cloud, where the robot captures an image of the 'identifier' of the object and sends it to the cloud.

The authors analyzed the inevitable problem of query method of the home robot in the usual home environment in USP 8307061 and USP 8380349. One of critical anticipated problems of these home robot patents is so simple. Google's home robot would pick up the identifiers of the object indiscriminately without any prohibition. User context study showed there could be a private object that user don't want that the robot 'searches' it as well as 'sees' it. Unfortunately, according to Google's current (published till in 2014) patent set; there was no extrinsic consideration about this privacy problem.

During the enfant stage of the technology in the S-curve, it is likely to miss something critical of the technical system. Acquiring and using the knowledge of the object might be the one of the crucial function of how the home robot works at home. But the anti-function, i.e. blocking/keeping the knowledge of the object should be considered as the other main function of the home robot. Focusing on the anti-function of current state of art, the authors suggested a special adviser to keep privacy of the users from home robot's indiscriminate query making by taking a picture of the identifier.

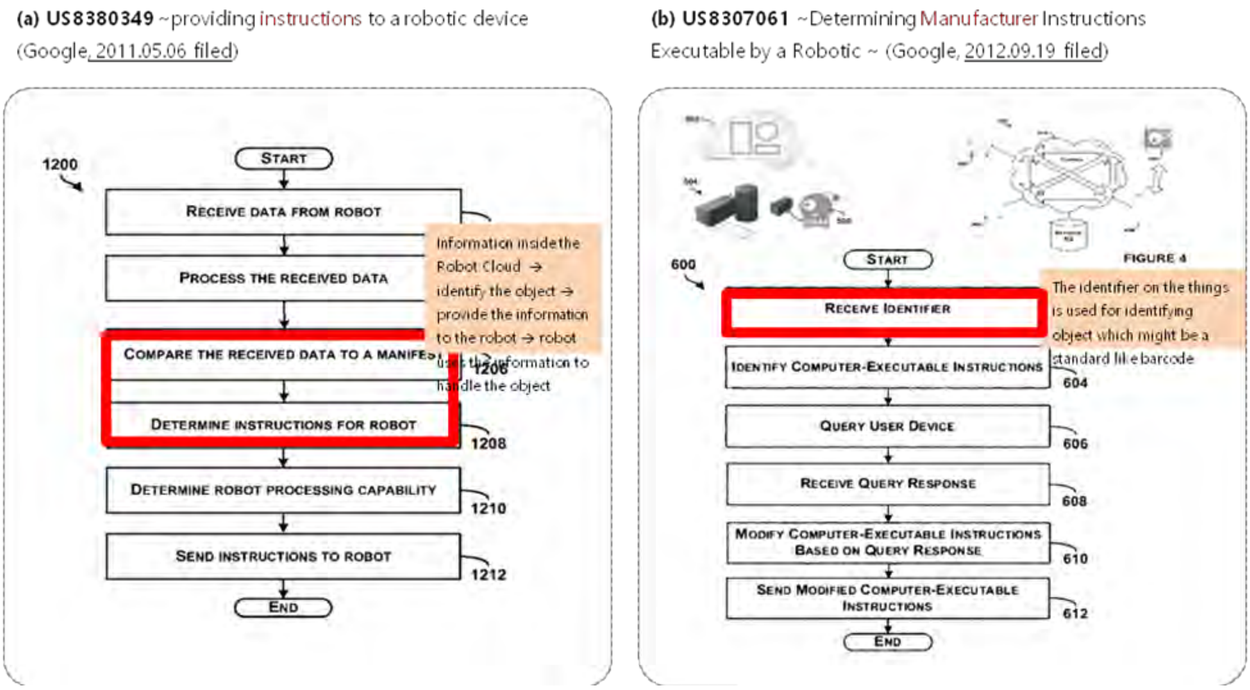


Fig. 6. Core concept of patent (a) US8380349 (b) US8307061

The authors designed a new scheme to allow the robot to recognize the objects and things and perform the query operation, only when the 'things adviser' agreed and/or allowed. After verifying the novelty through the real-time prior art search, the authors drafted the DOI(disclosure of invention) and revised the DOI through a peer review to file up the Korean patent application [10], of which US patents are under processing. There is another patents filed up directly based on the evolution map activity, infant care system of the smart home [11].

The smart home evolution map was delivered to the president of digital appliance business division. Evolution map influenced on the leadership to engage smart home strategic movement as well as to deliver Family Hub where connecting function is installed in the display on the refrigerator door in 2016.

2.3. Case 2. Home Robot

In early 2015, the authors started analysing more than 2,600 patents about home robot to predict evolution hypothesis and design corresponding patent concept design. The main direction was to discover 'new and useful function' of the home robot which was little bit far from mass-commercialization yet.

The authors could induce 14 different evolution driver hypotheses, where 3 evolution drivers were selected to figure out evolution maps as following: 1) Home robot learns me more and more, 2) Home robot has more engagement with me, 3) The value provided by the robot increases. Hypothesis "Home Robot learns me" was likely to evolve following steps denoted in Figure 7. In the 1st step, robot is insensitive to learn me. Step 2 corresponds to the present stage "robot starts recognizing me". A robot might understand air around me in the next evolution step 3. Efforts to create new concepts were focused on the step 3 because it was most likely to be the next stage of the 'present'.

The authors simulated various occasion with the aid of buyer's utility map presented in Figure 8 as well as user context studies presented in Figure 9. Buyer's utility map enlarged the vision just focusing on 'use' case only toward whole customer experience from purchasing to disuse as well as inherits. Otherwise, use context study helped breaking the limit of monotonic background, such as male, around age 30, spending very small time at home and so on.

Fig. 7. Home Robot Evolution Map - Robot learns me more and more

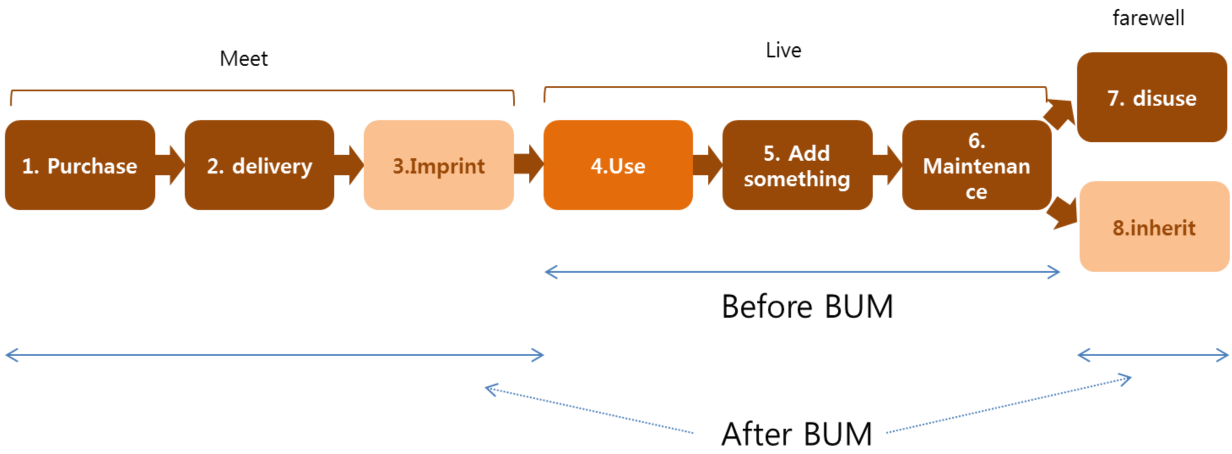


Fig. 8. Buyer's Utility Map for Home Robot

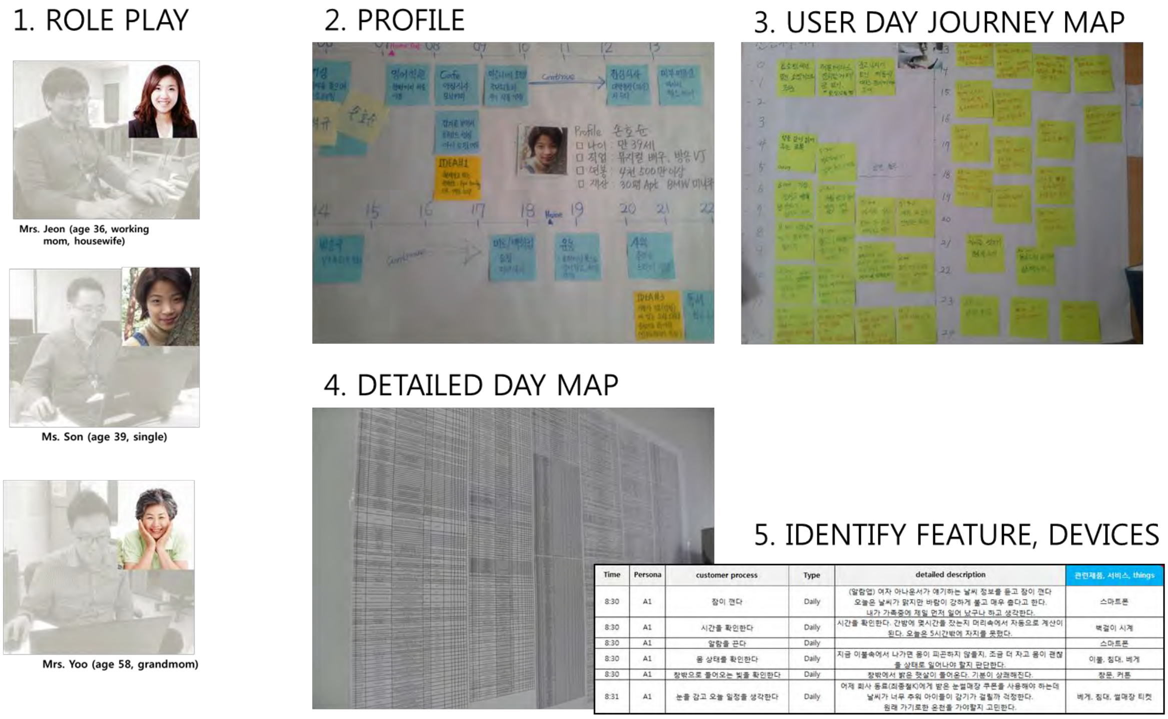


Fig. 9. User Context Study

To ignite 'new S-curve' on the next evolution stage, it is mandatory to imagine 'new function' which might attract the customers' purchasing desire the next stage. Since traditional TRIZ technique has intrinsic limitation to pick up users' unmet needs, persona, role playing, and customer journey map [7] in service design, buyers' utility map of blue ocean strategy [6] were applied to understand real situation of the user. The team investigated the profile of related persona, organized 1,101 conscious, unconscious daily home life event, which were used for investigate opportunity of new function at the 'air around me' steps.

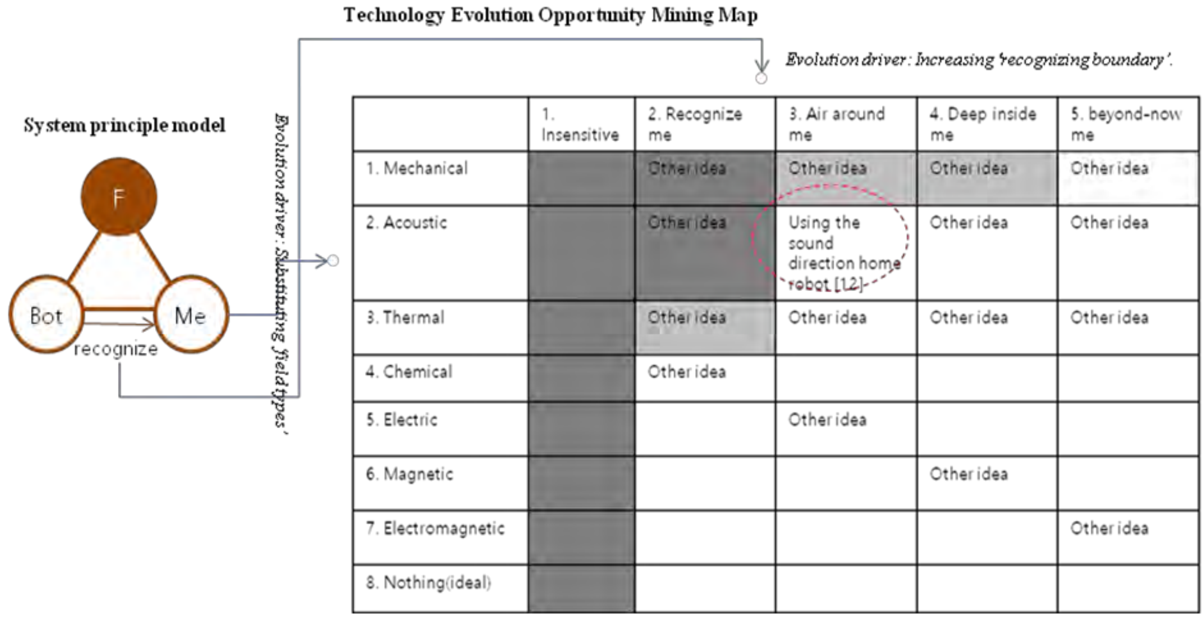


Fig. 10. New concept investigation frame based on TEOM

Figure 10 shows the journey to create the new idea to identify 'me' by the several energy sources where it comes from. Based on the big picture of evolution denoted in Figure 7, system function principle model could be drafted presented in Figure 10 composed of 'bot' as a tool, 'me' as an object, 'F' as an interaction field between the object and the 'bot'. Each element of the principles model follows its own evolution direction, for example, 'F' can follow 'substituting field types' such as MAThChEMEm scale. The authors combine the field evolution hypothesis with the high level evolution driver of 'bot learns me' to make an evolutionable-space so called TEOM [5]. After constructing TEOM matrix frame, the authors could evaluated each patents based on the new developed field evolution lines to 'recognize me'. Visualizing the evaluation results in Figure 10 shows not only the space where the competitors have already occupied (gray cell), but also the space where little/no competitors have occupied (white cell). The authors focused on suggesting new ideas for 'white space', where was 'free' from other intellectual properties. Sould direction idea came from the white coordinate, (3. air around me, 2. acoustic), of Figure 10, which filed up as a new patent after quick prior art search.

Based on combined approaches – evolution hypothesis and customer study, finally TEOM based focused ideation– the team were able to create 72 technically meaningful ideas which meet the next stage customer needs. Following 3 US/Korea/World patents are pending since 2015.

1. Using the sound direction home robot [12] - In providing speech notification, in the actual space, if there is an object related to the notification, the ring will come out in the direction of that object Provide voice notification as if it comes.

2. How to provide optional notifications [13] - Recognize and track feature points of multiple users through sensors, alarm function (indirect alarm / direct), per user (without disturbing others) Alarm) is executed.

3. Action Call [14] - Provide an action call that senses and expresses facial expressions and movements of opponents and users. It has the effect of further increasing the depth, familiarity of social interaction with the conversation partner.

There was one more important outcome of the home robot case study. The team members made their own evolution framework based on TEOM [5] and used it to make patent evolution portfolio map of patent developing engineering division, which means TRIZ evolution theory contributed strategic field of patent development, as well as creation of individual patents.

2.4. Analysing journey of case studies

Bottom-up vs. Top-down

There are 2 different ways to make a classification for massive patent data sets. Traditional way is top-down taxonomy; there is pre-defined technology tree structure and the individual patents are attached to the fixed structure. The other way is bottom-up classification; collect similar information and make a common name for the collected information step by step upward. Based on more than 20 experiences of patent evolution mapping of 50,000 patents collection, even if it is clear and fast to classify the big number of information, top-down classification has shown its limitation to re-organize and re-structuralize current function-tree structure to absolutely new ways, which is the essence of ‘inter-species’ technology evolution. On the other hand, bottom-up classification was very tedious and slow but it could deliver very flexible superimposing cluster structure, which enabled the participants to think more flexible. As the main purpose of the evolution map activity is not only analysing current technology but also foreseeing novel direction of future 'inter-species' evolution, bottom-up clustering is more recommendable than top-down analysis. At this point, the author recognized a need for a systematic tool supporting bottom-up analysis for evolution map, of which detail is described as following.

Human interaction vs. Information analysis itself

EMS (Evolution map system), the novel patent information clustering system was developed to facilitate bottom-up classification process. The philosophy of EMS is not just analysing information itself but also igniting human beings (the analyst team) to make more verbal communication which might enlighten novel evolution direction surpassing conventional paradigm. Patent information could be intuitively grouped through finger movements and active verbal communication between participants, which might induce new classification categories. In bottom-up classification, it is important to analyse the purpose and value of technology rather than technological feature itself. Since the purpose or value of technology is hardly described in the patent documents, it is inevitable to make a common name to describe various technologies under same clustering frame. The naming task naturally requires consensus among the team members. The 30 touches interface with 60 inch visual display of EMS allows 4 people to communicate very freely with their tongues as well as their fingers. EMS won a Samsung work smart award at the end of 2014 for its ability to effectively communicate among participants and classify a large amount of patent information. The information classification user interface was also filed as a patent [15].

Empathy vs. Technology

Even if the authors could find the direction of future evolution with the help of EMS, which was not enough to create specific intellectual property. It is possible to think the solution that is effective in the future only when participants understand the customer needs in the future. In the beginning of new S-curve, it is the core innovation to make all the 'necessary components' to meet 'new function [1]. Current main function might prolong its identity in the near future, but it is in evitable to introduce 'attractive function' to enchant the heart of the customers, which means the authors should solve two kinds of meta-problems. The one is to find out 'new functionality, the other is to complete the system without missing part according to system completeness trends [1].

In addition to the direction of the evolution of the big picture, it is crucial to understand where, when, why, for whom the product is to be used, i.e. the actual needs or hidden desire of users. Even if there are lots of variety of users, diversity level of usual Korean society is very narrow. To compensate the lack of diversity in Korean society, the authors implemented special tools such as customer journey map in service design[7] and BUM(buyers utility map) in blue ocean strategy[6] to promote understanding customer problems. Customer journey map promoted the team members to recognize 'un-known' lifestyle and 'unsaid' pain points of our customers following everyday life shadowing or role-playing. BUM helps the team members to think the other part of product before and after 'usual using'.

Analyzing patents is a rational activity. On the other hand, looking for pain points that customers could hardly tell is emotional activity. In the beginning stage of the S-curve, it is most critical activity to complete 'necessary elements' to deliver 'new function'. The first activity is to recognize what function should be delivered. The second activity is to rationalize what elements should be included. The first question could be solved by trying empathic activity, in the other hand; the second question could be solved by patent surveying with assisting with TRIZ evolution theory. The approach of this study, which harmonized emotional activities after rational activity, helped researchers obtain clearer scenario of future.

Impact on the Leadership and the Strategy

The smart home evolution map was delivered to the highest leadership of digital appliance business division, and it could turn the leader's vision toward more innovative way. New development team had been engaged after reporting smart home evolution map. The first outcome, "Family Hub Refrigerator" could be delivered to the market with the full support of the highest leadership of the appliance division. The keynote speech of Mr. Yoon, BK, and Samsung CEO in CES 2015[16] reflected the core part of smart home evolution map delivered to him around October, 2014 by the authors.

The process of home robot study based on TEOM [5] influenced their own framework to make patent portfolio map, which means TRIZ evolution theory contributes patent strategy, as well as creation of individual patents. For a long time, TRIZ has been well-known methodology of problem solving to Samsung people. The core value of this study is to prove the strategic value of TRIZ evolution theory to the highest leadership of Samsung electronics.

3. Conclusions

To discover promising patents in the near future in advance invention process based on evolution map was designed. In the beginning, large numbers of patent information were classified and corresponding evolution hypothesis map was visualized based on TRIZ evolution theory. Multi touch information-user interface EMS was developed to assist classifying lots of patents and visualizing evolution trend. After visualizing evolution map, the authors could deliver challenging evolution direction as well as tangible disclosure of invention with minimal trial and error. 2 case studies prove how evolution theory have contributed to the big strategic jump of smart home and home robot business of Samsung electronics. The authors expect that evolution map based in advance invention would guide anyone who wants big strategic jump and tangible intellectual properties. The core value of this study is to prove the strategic value of evolution theory on the big picture of R&D beyond just solving mini- problems of the current field work.

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FROM PROBLEM TO OBJECTIVE – COMPLEMENTING TRIZ WITH NLP

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Abstract

Neuro-Linguistic Programming (NLP) has been found to be similar to TRIZ in many aspects, as described by Mann, Kozyreva and others. NLP is often presented as a methodology of recognizing patterns of effective behaviour (or even *patterns of mastery*), which relates closely to Altshuller's research on innovation principles and trends of evolution - the foundations of classical TRIZ. Several ideas coming from NLP area have been successfully merged with TRIZ tools – for instance sensual descriptors (visual, auditory, etc.) may be applied jointly with the system operator.

This paper presents problem formulation approaches starting with cause-effect analysis and addressing works of Litvin, Souchkov and others (including IST/SOLL approach). The discussion refers to SMART criteria, commonly used for evaluating business goals, and *outcome well-formedness* criteria indicated in NLP literature, highlighting positive goal formulation and ecology aspects.

Positive goal formulation is of primary importance, because stating what we *don't want* – which is a typical output from cause-effect analysis of disadvantages – pushes us away from the problem, but not necessarily moves us closer to the solution. On the other hand, stating what we *do want* is like pulling towards a solution, which aligns with the concept of Ideal Final Result as a convergence point in the solution space.

Ecology as a science analyses interactions between organisms and the environment. NLP uses this name for describing a frame of reference for consequences resulting from any decision and it recommends several questions to be asked within a personal context to identify and evaluate such consequences in advance, e.g.: *am I ready to accept and sustain this result?* or *would I accept this result if I could have it now?* Such holistic approach might be adapted for evaluating planned changes within a technical system, which corresponds to moving along time axis of system operator and anticipating secondary problems.

Keywords: Neuro-Linguistic Programming; goal formulation criteria; secondary problems.

1. Cause-effect analysis in TRIZ

Cause-Effects Chains Analysis (CECA) method was developed in GEN3 in 1990s and, being taught during certification workshops accredited by MATRIZ, it might be considered the "official" TRIZ approach to cause-effect analysis. The method, as described by Litvin and Akselrod in [1], starts with determining undesirable effects (*target disadvantages*) that should be eliminated from the system. Then, in several repeated steps it aims to identify factors causing particular effects, what results in building chains of *intermediate disadvantages* until reaching a cause reflecting a law of nature or a business constraint of particular project, which is considered a *root cause* and stops analysis of a given chain. Resulting diagram consists of such chains, possibly including logical operators (AND, OR) to reflect relations of contributing causes or loops representing positive feedback among undesirable effects in the analysed system.

Although the root causes cannot be eliminated, as a rule, they indicate main factors influencing the system and also define boundaries of the model. The expected outcome of the CECA process is identification of a set of causes, called *key disadvantages*, elimination of which would result in removal of the target disadvantages specified for the project. Such key disadvantages usually reflect deep causes of primary nature and they are supposed to inspire strong solutions, however transition from identified key disadvantages to problem formulation is not supported by original CECA. Moreover, rigid perception of causes as disadvantages seems to be an inherent limitation of this concept, as the logical inversion of a condition defining a disadvantage may describe an *advantage*, which cannot be properly represented in the CECA model. This particular drawback was identified in [2], during proposed conversion of CECA diagram into set of logical functions to support algorithmic selection of causes having the greatest impact on target disadvantages.

Among several improvements to the original CECA procedure, Yoon [3] proposed a retreat from disadvantage-only perception of causes as well as systematization of the analysis process, yielding additional benefit of discovering hidden causes. This approach uses chains of causes composed of interleaved descriptions of *conditions* and *actions*, so that adjacent causes of the same category (condition – condition or action – action) indicate a missing element of the opposite type, which should appear in between. Another bonus of this method comes from the requirement to indicate specific parameters and values for conditions in the diagram, leading to unified and more comprehensive description of the problem.

A new opening to cause-effect analysis was made by Souchkov [4] with Root Conflict Analysis method (RCA+). The main conceptual shift of this approach, with respect to CECA, relies on explicit modelling of both negative and positive results of the causes identified during system analysis. Also, the usual *why?* question is rejected as being insufficiently precise. This change of perspective provides a natural way for describing causes, which cannot be properly modelled within CECA realm. It also expands the contents of the model and enhances the perception of the problem situation. Finally, the causes with both positive and negative effects represent conflicting requirements, which indicate opportunities for inventive solutions and directly support transition from the analysis to problem formulation stage.

The methods for identifying contradictions in cause-effect models, including CECA and RCA+, are analysed by Dobrusskin in [5]. One of the proposed procedures searches for conflicting requirements (concerning the same parameter of the same component), located in different branches of the causality graph, which are not explicitly handled by RCA+. Such requirements should be merged with attention, because apparently opposite conditions coming from different contexts do not have to be complementary in a logical sense [2]. Another procedure presented in [5] demonstrates the use of IST/SOLL approach, which requires both the current state (IST) and the desired state (SOLL) to be described with specific values of a control parameter.

The described methods vary from investigating what we *don't want* (CECA), through indicating what we *do want* for some reasons and *don't want* for other reasons (RCA+), to specifying what we *particularly do want* in the analysed system (IST/SOLL). And the latter attitude clearly directs attention towards specific objectives, increasing chances for proper problem formulation.

2. Selecting problems for solving

Development of tools for analysis of engineering systems for problem statement was the main subject of the TRIZ Developers Summit 2007, which took place in Moscow. The presentations covered diversified topics, including scientific beliefs, sustainable design, social-and-engineering systems, use of resources and so on. Following the subject, the majority of papers referred to different aspects of problem statement and in the context of this research the works of Bystritsky, Gerasimov, Ivanov, Kozhevnickova, Litvin, Pinyayev and Rubin (alphabetical order) appear to be the most interesting.

An overview of approaches to problem selection is given in [6], with references to literature and various tools. Proposed classification distinguishes *review of options* and *directed search* methods, with further decomposition of the second group. One of the mentioned methods is the Algorithm for the Selection of Engineering Problems (AVIZ), described in detail in [7]. Retrospective report on changing focus of TRIZ research as well as tools emerging from that evolution appears in [8], illustrating how the area of interest moved from solving technical problems to forecasting future products. The subject of alternative technical systems as inspirations for formulating innovative problems is addressed in [9], using the example of fusion of a reflector telescope with a refractor telescope achieved by Maksutov.

Practical discussion on selecting the *right problem* is provided in [10], with a conclusion that in real-life situations one is unlikely to be able to select such problem in advance. Methodical approach is then prescribed for selecting problems using the results of the cause-effect analysis as the input. Proposed method employs working through cause-effect chains and identifying possible ways of preventing the results from manifesting themselves for each particular cause, which is based on the concept of *negating undesirable action statement*, devised by Ponomarenko in [11].

3. NLP and TRIZ

Neuro-Linguistic Programming (NLP) is sometimes described as a methodology of recognizing and using patterns of effective behaviour, which is clearly similar to recognizing and using patterns of problems (contradictions), patterns of solutions (inventive principles, standard solutions) and patterns of development (trends of systems evolution), constituting main foundations of the classical TRIZ. Comprehensive introduction to NLP is given by O'Connor and Seymour in [12], covering all major concepts and techniques. Online article by Hall [13] presents brief history of the NLP and Neuro-Semantics, crediting the roots of both to Polish linguist and philosopher Alfred Korzybski, who formulated the concept of General Semantics. Bodenhamer, in turn, gives compact resume of NLP goal formulation criteria in [14].

The key to NLP is realizing that people only interact with the world through senses and each of us has our own internal model of the world, built upon sensual signals transported by the nervous system and transformed by perception filters formed by preferences and beliefs coming from unique personal life experience. This duality was pointed to by Korzybski in his famous quote: "*The map is not the territory*", as each of us uses private representation of the world and we only respond to our own perception of reality. This implies important rule regarding communication: *meaning of a message is actually defined by the receiving person, regardless of original intent of the message sender*.

Specific personal perception of the world comes from differences in sensitivity and preferences to stimuli from particular senses (visual, auditory, kinaesthetic, olfactory, gustatory), jointly referred to as VAKOG. Productive cooperation among people with strong preferences for different input channels could be a challenge if the visual person *cannot see the merit* and the kinaesthetic person *doesn't feel comfortable with the idea*, which actually *speaks for itself* to the auditory person. Simply put, people are different and interpersonal communication should respect that diversity. Or using words of Anaïs Nin: "*We don't see things as they are – we see them as we are"*.

Moreover, several repeatable sets of strategies have been identified for various aspects of interaction with the world, called *meta-programs,* which influence our behaviour in typical situations. They are usually described in pairs, such as: perception (general / detailed), relations (similarities / differences), attitude (consensus / objection), approach (procedures / options), motivation (towards the goal / away from problem), authority (internal / external), etc. Meta-programs strongly relate to professional predispositions – for instance Quality Assurance department would probably prefer to hire a person being inherently oriented towards *details*, *differences* and *objections* rather than *general impressions*, *similarities* and *consensus*.

Similarities and possible interactions between NLP and TRIZ are described by Becker and Domb in [15]. NLP is also addressed in reports on creative methods by Zusman and Zlotin [16] and, with much more details, by Mann and Dewulf [17]. Later works of Mann and Bridoux [18, 19] have been integrated and shown in wider perspective in the book [20]. Examples of merging NLP techniques with TRIZ cover the 3D extensions to system operator with sensual description (VAKOG), situation perception perspective (*association* vs. *dissociation*) and Dilts' logical levels (*environment, behaviour, capabilities, beliefs, identity*). The map-territory duality is also explored by analysing separate problem models as perceived by various participants of a problem situation. Finally, an extensive review of matches and possible applications of NLP techniques in TRIZ, with the focus on overcoming psychological inertia, is given by Kozyreva in [21].

4. NLP and problems

NLP offers systematic approach to problems, described with specific perspective and language. Problem is perceived as a gap between the current state and the desired state [14]. Hence, a change of state is required to bridge the gap. Planning for that change is aimed at achieving particular goal (outcome) and so it focuses on obtaining the solution, rather than exploring in-depth the problem. Main guidelines for this approach, dubbed in literature as *outcome well-formedness criteria*, are briefly described below with some additional remarks.

Positive goal description is of crucial importance for two reasons. Firstly, human brain is known to be deficient in processing negative denotations, because *lack of something* inadvertently draws attention to that *something*. This confuses unconscious mind and thus reduces processing potential of the brain [12]. Secondly, stating *what we don't want* is convenient for describing problems, but it does not indicate *what we do want* and therefore is simply impractical for describing goals (picture yourself ordering a drink with the use of this strategy, for example).

Specific goal description is required to build and verify proper understanding of the goal within particular context (*what*) and timeframe (*when*). It is also necessary for formulating quality criteria for evaluating the outcome. To provide usability in technical or business situations, the generic NLP question *how will you know, that your goal is achieved?* should be answered by indicating some control parameters of the system together with their required values. Simply put, it is easier to reach and to confirm reaching a goal, if it is clearly defined and scheduled in time.

Size of the goal is an important concern, because NLP cares about sensations (also unconscious), as they may heavily influence people's performance. If the objective is too big, it might be seen (or heard, or felt) as overwhelming and being unreachable. Such objective should be decomposed into smaller parts using identified blockers or constraints (what is known as *chunk down*). If the goal is too small, however, it might be perceived insufficiently important and thus not appealing. Such goal should be considered as a fragment of a bigger, more valuable goal (*chunk up*). These mental operations are similar to those used in TRIZ for adjusting granularity of component model and they share common objective to work with objects of sizes adjusted for particular purpose.

Scope of control also needs verification, as it would be pointless to pay attention and efforts to matters remaining beyond control. Therefore it should be investigated to what extent one is able to initiate and control the change from current state to desired state. Diagnosis of insufficient control may indicate that the problem has been improperly selected, formulated or scaled, or the approach to the problem should be changed to find a new perspective. Such diagnosis may also relate to identification of necessary resources. And classic NLP question for situations when something seems impossible (unavailable, forbidden, etc.) is: *what would have to happen to make it possible?* This is a great game-changer, as it immediately switches perception form inability and limitations towards activity and solutions. It also instils an optimistic and powerful idea, that presuming anything to be possible is much more useful strategy than the opposite one.

Ecology of the goal is also described as the *frame of consequences*. This stage of verification is aimed at anticipating and analysing in advance consequences of the intended change in various aspects and the main criterion to validate is *ecology* or *appropriateness* of the future situation. Mental projection used in this technique should be tuned to detect conscious objections, typically articulated with *yes, but…* prefix and for early warnings coming from unconscious mind, such as *hunches* or even kinaesthetic manifestations, recognized as *feelings in the guts*.

This looks very personal and very non-technical, but it is actually similar to analysing future views of the system, super-system and sub-systems using TRIZ system operator. To explore this analogy we will use Dilts logical levels, mentioned before. Technical descriptions address system structure (components) and operation (functions), which fit into *environment* and *behaviour* levels, related to facts. Within the frame of ecology, NLP also addresses higher levels of *capabilities* and *beliefs*, which relate to strategies and values. This broader perspective allows for anticipating not only if the system will survive considered change, but also how this change will contribute to higher-level goals to develop the ecosystem.

One of the questions used to verify ecology of a goal is: *would I accept it if I could have it now?* It throws a direct challenge to the super-computer of unconscious mind, which queries personal knowledge base and the answers may signal expected difficulties (i.e. secondary problems) or, even better, particular precautions or adjustments required at sub-system or super-system level (i.e. candidate solutions of secondary problems). Moreover, multitude of questions suggested in NLP literature for verification of considered change within the frame of consequences may be nicely generalized with four *Cartesian Questions*, supporting systematic analysis of pros and cons:

what will happen if I do that?	what won't happen if I do that?
what will happen if I don't do that?	what won't happen if I don't do that?

5. NLP and SMART criteria

SMART (sometimes written as S.M.A.R.T.) is a mnemonic acronym indicating important criteria for defining goals and objectives, developed in the management area. It is usually expanded as: *Specific – Measurable – Achievable – Relevant – Time-related* (with several other versions in use). Let us check, how these criteria compare with NLP guidelines presented in the previous section.

Specific – requires to aim at defined result or area of improvement	directly fits with NLP postulate of specific goal description
Measurable – requires some measures or indicators of the progress (sometimes decoded as *Motivating*)	fits with NLP criteria for verifying if the goal has been achieved and chunk up / down technique
Achievable (also *Attainable*, *Agreed*) – calls for setting objectives within the feasible reach	fits with evaluating size of goal, scope of control and NLP perception of the goal / problem duality
Relevant (also Realistic, Resourced, Reasonable, Responsible) – has several divergent variants	fits with NLP care for required resources and appropriate size of the goal
Time-related (also *Trackable*, *Time/cost limited*) – requires to specify a timeframe for the objective	fits with NLP specific goal description, which also covers scheduling

As it could be seen, NLP guidelines for goal formulation cover all the SMART criteria and neither *positive goal description*, nor *ecology frame* appeared in the resultant mapping. Indeed, these two address psychological aspects of positive and holistic approach, which belong to higher level of perception of the problem solving process than managerial aspects jointly described as SMART. And because NLP is built upon the concept of levels, these criteria should be called *meta-SMART*.

Also, the SMART criteria appear insufficiently precise for technical applications, because if a goal is actually *measurable*, it is also *specific*, and if a goal is reasonably considered to be *achievable*, then it should be considered *realistic* as well.

6. Example

To illustrate benefits of using blended TRIZ+NLP approach we will use real-life example.

Provider **A** leases offices to company **B**, which uses this space for own purposes and subleases some segments to its subsidiary company **C** and other tenants. In addition to bare infrastructure (space and installations), **A** provides basic services (e.g. security). On top of that, **B** provides own services to tenants (e.g. cleaning). Tenants are billed for dedicated space segments as well as for using shared space (kitchens, toilets, etc.) and services. After some time **C** moved part of its team to another location and wants to decrease the leasing fee, while **B** insists on sustaining payments at the agreed level.

Analysis of the situation led to identification of the system comprising infrastructure, operator and services (including space) and super-system, as it is depicted in Fig. 1. Main useful function of the system has been indicated as: *system supports tenants* (i.e. system provides services maintaining operational capabilities of the tenants) and physical contradiction related to function *pays* reads as:

- leasing fee of tenant **C** *should be decreased* to enhance profitability of tenant **C**, but
- leasing fee of tenant **C** *should not be decreased* to maintain profitability of operator **B**.

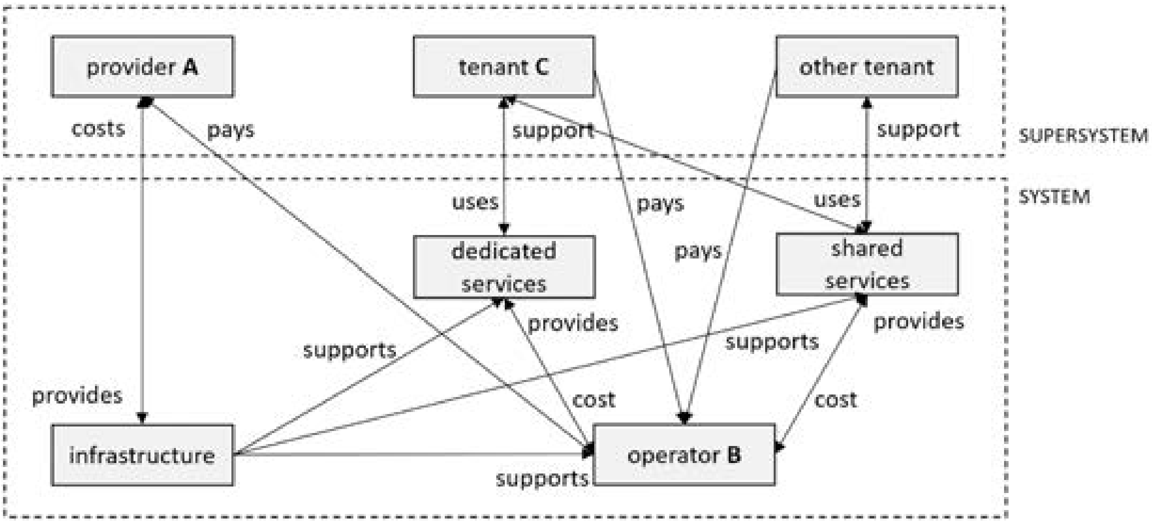

Fig. 1. Functional model of example problem situation

This situation may be approached with separation principles or other TRIZ tools, but we will take NLP-style holistic perspective instead. Since operator is not interested in changing the agreement, it is a perfect occasion to ask: *what would have to happen to make it possible?* Or more precisely: *on what conditions **B** would accept decreased leasing fees from **C**?* Or using chunk up technique: *what is a higher-level objective, which both contradicting demands jointly contribute to?*

This approach extends problem perception: tenant **C** is a subsidiary company of the operator **B**, so that decreased profitability of **C** would negatively influence **B** as well. This relation between the companies was not explored during function analysis and, consequently, it does not appear in the diagram. Now, instead of solving the problem of decreasing / not decreasing the payments, we may aim higher: at *increasing profitability of **B**+**C** ecosystem*.

Such reframing of the problem moves focus onto possible ways of using dedicated services freed by **C** to gain benefits outperforming those coming from regular leasing fees. Candidate solutions generated with this approach addressed boosting people's performance by converting the unused rooms into shared space and adapting it for more comfortable work (e.g. by installing phone-booth cubicles), for rest (e.g. creating nap zone) or for leisure (darts, table tennis etc.).

7. Summary

TRIZ approach comprises system modelling (e.g. with Function Analysis or Flow Analysis tools), identifying target disadvantages and tracking causality (e.g. using Cause-Effect Chains Analysis), selecting disadvantages to be eliminated, formulating problems for solving, evaluating candidate solutions against project constraints, implementing selected solutions and dealing with secondary problems, which usually appear in the implementation stage. This process requires use of many tools and if secondary problems are to be analysed in advance, then additional tools should be used, such as system operator or Size-Time-Cost operator.

NLP perceives problem to be *improperly defined objective* and it aims at achieving the objective (intended outcome), instead of focusing on the problem, while the ecology (appropriateness) of the desired target situation is among the key criteria evaluated in the very beginning. This approach tightly reflects the idea of attraction towards Ideal Final Result, being fundamental to the whole TRIZ methodology. Although NLP doesn't offer any technical tools supporting problem solving process, it provides powerful psychological tools instead, supporting people in that process. And as long as people are involved, psychological aspects will influence effectiveness and efficiency of their behaviour.

As it was shown, classical CECA ends with indication of key disadvantages and does not support transition to problem formulation stage. This transition may be facilitated using NLP techniques. It seems therefore advisable to include selected NLP concepts into TRIZ training programmes in order to familiarize future innovators with:

- opportunities and threats coming from sensual preferences and meta-programs,
- power of unconscious mind and its deficiency in processing negative notions,
- formulating goals positively and using the frame of ecology,
- scaling objectives to perceive them appealing yet achievable,
- using eye-opening and game-changing questions from NLP toolbox.

8. Conclusions and further work

In conclusion:

TRIZ is about recognizing and using patterns and NLP is about recognizing and using patterns.
But, first of all, they are both about people, who are causing, analysing and solving problems.

TRIZ started from technology problems and it developed its own psychological tools. NLP started from psychology problems and it proved its usability in business and technology.

Many concepts of TRIZ and NLP have been used together so far, as compatible or complementary.
Problem perception and teamwork support seem the most prospective areas for fusion with NLP.

Benefits expected from better formulation of problems as well as better selection and communication of team members justify further research on blending NLP techniques into the TRIZ world.

Acknowledgments

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GENERATIVE INVENTIONS

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Abstract

Architecture of Artificial Intelligence system for fully automatic generation of new inventions is discussed. The goal is to automatically create potentially possible inventions and socio-technical systems by running generative A.I. algorithms on multidiscipline knowledge bases.

Keywords: generative inventions, computational creativity, artificial intelligence, TRIZ, novelty propagation

1. Automatic generation of inventions

Unlike traditional engineering workflow: "there is a problem – let's find a solution", new approach suggests use of creative A.I. software for automatic generation of structures of technical products, automatic formulation of potential problems and their solutions in advance. Many of generated solutions will have enough novelty to be considered original inventions. Before focusing on actual design of creative A.I. software, let's answer three questions, which are often asked by human inventors: first, can computer invent; second, do we need creative A.I.; third, will A.I. replace inventors, engineers?

We answer first question with solid Yes. In ingenious theoretical work [1], published before first electronic computer was build, Alan Turing proved, that hypothetical computing machine can run *any* algorithm, no matter how complicated it is. Simply put, if we can write a code to simulate inventive logic, computer will be able to invent. Of course, in addition to logic simulation, we need to describe a universe of physical, technical and biological objects and all types of relations between them. We need to make computer understand, that, for example, function *to cool chip set* of smart phone is directly related to following functions: *move atoms and molecules, reduce voltage, insulate from environment.* Complexity of knowledge description used to be really prohibitive, but with recent advances in semantics the issue of representing physical, chemical, biological and technical worlds in computer memory is not a big deal anymore [2]. It's simply a matter of proper funding and normal project management.

Increase in productivity of creative workers is the answer of second question. We need creative A.I., because even the best research engineers and designers have limits in their performance. In generative inventions operation *to invent/design*, which is time and resource consuming, is replaced with much more simple operation *to find*. Instead of designing new product from the scratch engineer types *find products with function F,* and the system brings on the screen all artificially created inventions with function *F* and constraints *C.* Because needs and related inventions had been generated before design project was assigned to the engineer, he/she can quickly compare different options in order to choose the most suited invention for further refinement.

Third question has following answer: creative A.I. won't replace inventors and research engineers; instead, introduction of generative inventions will increase demand for knowledge engineers and domain experts. Although computers perform mathematical operations much faster than humans, professional mathematicians didn't disappear; on the contrary, demand for them continues to grow. Human creativity is still needed to write code for creative machines and adopt ideas, generated by A.I., for real world. Human intelligence and A.I. will co-exist, at least, for a period of time, when creative machines are programmed by human mathematicians.

2. A.I. power is rapidly increasing

Sudden increase in demand for A.I. technologies can be explained not only by the fact, that machine learning and predictive analytics boost profitability of large corporations, but also by more important effect – A.I. opens new opportunities for technological and social innovations.

This is why venture capitalists rushed into A.I. en masse, making this area red hot. In the report "Predictions 2017: Artificial Intelligence Will Drive the Insights Revolution" Forrester Research expects 300% increase in industry investment in A.I. in 2017 compared with 2016 [3]. Modern A.I. truly understands meanings of words, phrases and texts, it also can learn new things by using semantic and neural networks. Customized microprocessors that mimic the structure of human neurons are hitting the market, further accelerating evolution of true artificial brain. A.I. technology is available, venture capital is moving in, all together making this project practical. Generative inventions concept is in the air. It's inevitable as a next logical step in A.I. evolution.

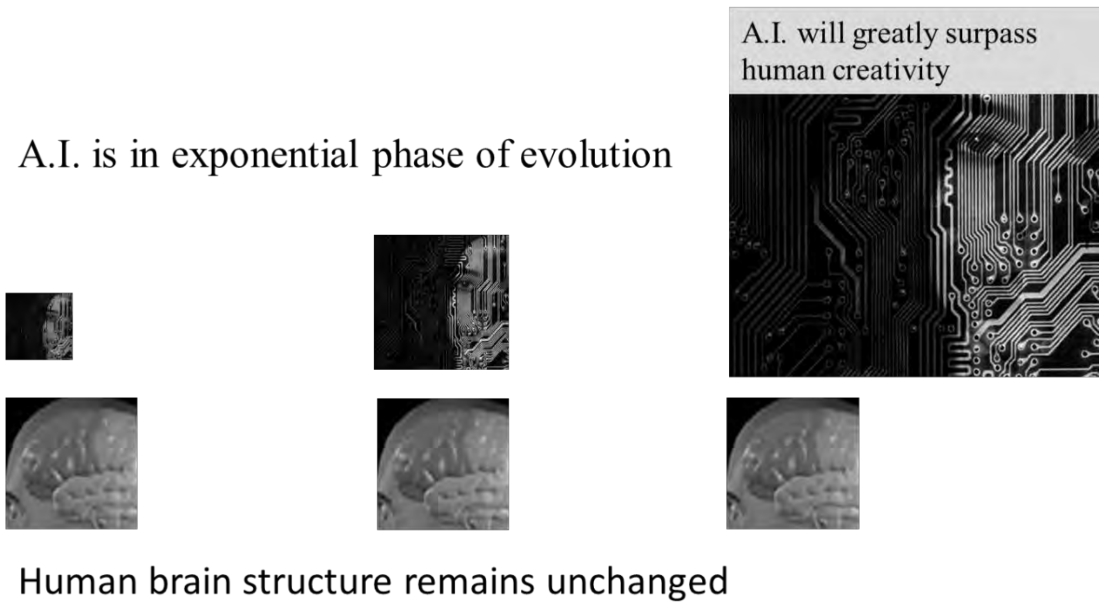

Fig. 1. Exponential evolution of A.I.

3. A.I. as creative partner

The concept of generative inventions is quite different from methodologies and software tools that support innovative thinking. Mind mapping, TRIZ-based software systems teach users how to think out-of-box or provide engineers with refined knowledge, which may help solve inventive problems. At the end, there is a human user, who formulates the novel solution.

Generative invention means, that A.I. system not only finds important facts, effects, analogies, it also generates creative solutions *on its own*. In this case A.I. is not a tool, it is a creative partner. It plays active role as a co-creator of novel technologies. Human inventor and creative A.I. have different strengths and weaknesses, making this partnership pretty logical (Table 1).

Table 1

Humans vs. A.I.: strengths and weaknesses

Feature	**A.I. in 2017**	**Humans**
Concept generation	+++++	+
Solution acceptance	+	++++
Intuition	+	++++
Overcomes Inertia	+++++	no

A.I. as generative inventions: can produce much more conceptual designs for different constraints; has no psychological inertia problem. Humans: can judge generated concepts with cultural/corporate/personal filters; may apply intuition; are able to adopt concepts to needs of hierarchical dynamic world.

Despite much larger knowledge base and much faster generation of novel designs the main purpose of creative A.I. system in form of generative inventions is to empower human engineers, designers, inventors and help them discover new technological opportunities.

Generative inventions has roots in Invention Machine™ project, initiated by research company IMLab in Minsk and later funded by IMCorp in Boston, but there is a principal difference: the main idea of Invention Machine project was to develop intelligent software to support inventive process. In this case software works as an intelligent assistant, helping engineers apply scientific effects, TRIZ-tools and Value Engineering Analysis [4, 5].

Generative inventions project makes next logical step by focusing on automatic creation of new technical ideas, concepts, solutions, acting as a creative partner of human inventors.

4. Architecture of A.I. system for generative inventions

In today's totally computerized world everything is connected and everything tends to be intelligent. Modern technical systems are networked, interact with each other and human users [6]. To reflect this thesis, we suggest to use the term intelligent socio-technical system (Fig. 2) instead of engineering/technical system [7].

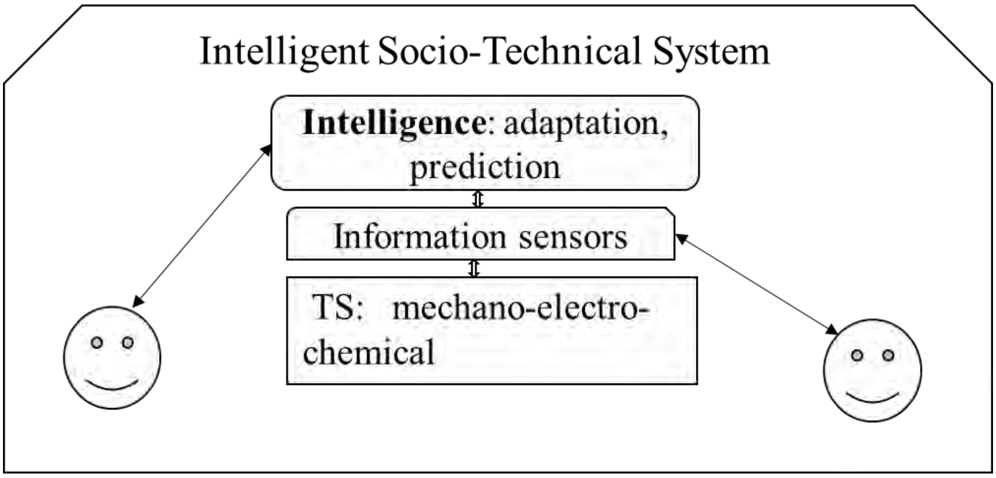

Fig 2. Intelligent Socio-Technical System

The architecture of A.I. system for generative inventions (Fig. 3) includes three main knowledge bases: first k-base consists of existing and predicted technical, social needs and trends; second contains abstract technology shells representing different types of intelligent socio-technical systems; scientific effects and their technical implementations are presented in third k-base.

Technology shell: new ideas, generated by inventors or TRIZ-experts at conceptual phase of design, have a very high level of uncertainty. This is why many promising ideas are rejected at this phase, because they are based on unfamiliar effects, exotic materials or have weak parameters.

TRIZ helps find ideas, which often have high potential value, because they resolve contradictions and are close to ideal solutions, but still a wide gap exists between such ideas and acceptance of them for further development.

To narrow the gap between novel idea and its acceptance we introduce technology shell as a structure, which includes main casual relation in semantic form of Subject-Action-Object, values of absolute and relative parameters, abstract solutions for desired and current parameters matching, idea validation info (research and practical levels), related problems.

When A.I. system finds a novel idea in a form of scientific effect or technical solution, it fills as many parts of technology shell as possible. In ideal case by filling all parts of the shell A.I. system will not only find novel idea, it will be able to describe technical solution ready for experiments and possible practical implementation. It is much easier to accept unusual idea by an engineer if the idea is described in terms familiar to the engineer, together with all critical information about parameters, experiments and prototypes.

Let's fill the technology shell for concept: *carbon nanotubes - cool - microchip* of a computer or a smart phone.

S-A-O: Subject X - cools - microchip
Conceptual idea 1: carbon nanotubes – cool – microchips
Parameters: thermal conductivity of carbon nanotube is several times better than cooper.
Parameters matching: n/a
Problem: weak interaction between carbon and metal of chip is a barrier for heat flow
Solution: add organic molecules to create strong covalent bonds between carbon nanotubes and metal of microchips
Parameters of problem solution: six-fold improvement in the heat flow between metal and carbon nanotubes
Validation, research: group of physicist with the Lawrence Berkeley National Laboratory's Materials Sciences Division and two former Intel researchers [8]
Validation, practical use: not found
Suppliers of technology: not found
Amplifiers of main parameter: heat flow between carbon and nanotubes. Fields, structure, adaptive heat management. Transition from carbon nanotubes to graphene.

Validation of the idea is based on results of experiments: six-fold improvement in the heat flow, which is very good, and high reputation of Lawrence Berkeley Lab.

There can be many shells with different levels of idea validation for function *cool microchip*. For example: water in microfluid channels cools chips 60% more efficient than air, validation – research and experiments by industry [9], phase transition effect cools smart phones, validation – by Fujitsu [9], self-cooling graphene transistors may reach 100GHZ without external cooling, validation – minimal, this concept is at discovery phase, but looks very promising [10].

Knowledge base in form of technology shells provides a unified model for new ideas generation by direct analogy and also increases chance for acceptance of new ideas by including validation data.

Generative Inventions Algorithms module performs following high level operations:

- Needs and technology shells matching: existing needs are matched with technology shells and/or scientific effects. By filling abstract shells with scientific and technical knowledge, the module produces initial inventions.
- Performance increase: parameters of main function of generated initial invention are increased by using knowledge base of abstract amplifiers. This is a very important operation, because many innovative ideas are rejected due to low performance of novel concept. Amplifiers help to refine original idea and make it more practical and acceptable.
- Variations generation: different versions of the invention are generated: portable solution, modification for mass use, special design to reach record performance, for example, in sport.
- Prediction of future needs and problems: by using hierarchical social and technical needs, robust technological trends together with newly published results of scientific research the module repeats generative inventions process, creating novel conceptual ideas for predicted needs.
- Novelty propagation: when researchers discover new scientific effect, it usually takes many years before it is used to solve engineering problems. Same happens when engineers find great technical idea, which potentially can be used in many different areas, but due to lack of understanding by engineers from other domains it may take long time

to spread the idea.

Novelty propagation is an A.I. algorithm, which takes novel technical solution, new effect or recently discovered material, then finds areas where this new knowledge can be used in principle and by filling technology shells generates all possible inventive concepts, based on novel solution or new effect/material.

Full operational version of novelty propagation algorithm will dramatically speed up implementation of new discoveries to solve technical problems.

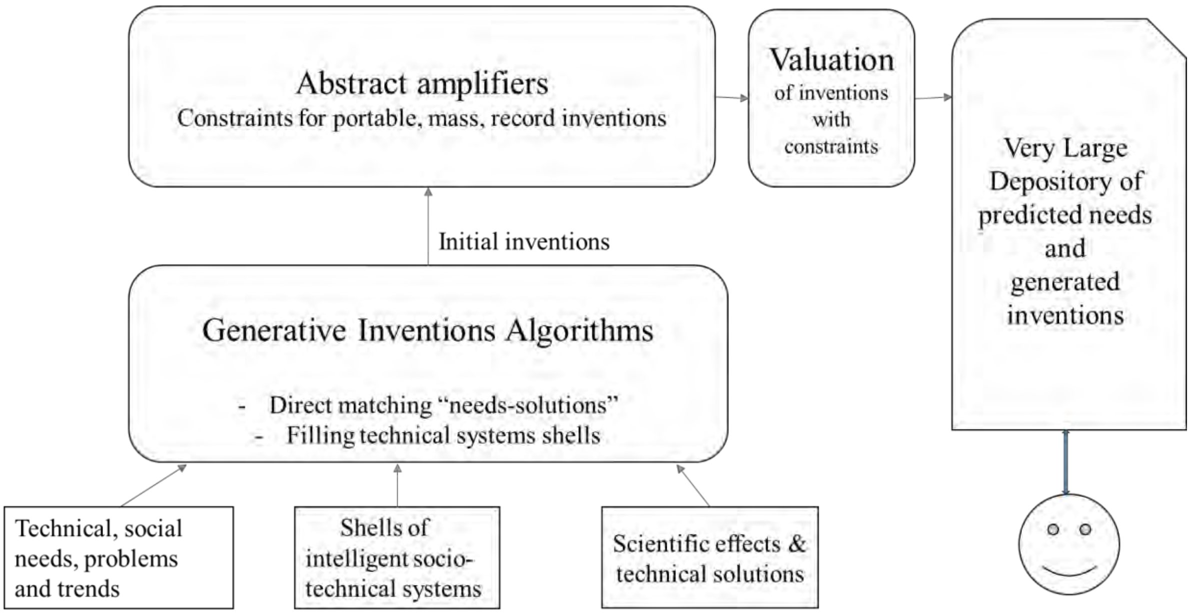

Fig 3. Architecture of A.I. System for Generative Inventions

At the end of inventive process A.I. system creates an easy in use very large depository of predicted needs, potential inventions and technical solutions. End users communicate with A.I. system by using natural language interface. Human users make contribution to joint creativity process by performing analysis of generated ideas and by planning future experiments.

Communication between creative partners has one serious problem to be addressed. The knowledge base of A.I. system is several orders of magnitude larger than any individual can learn during entire life span. It means, that many inventions, generated by A.I., will be based on knowledge not familiar to human user.

We discovered this problem back in 1997 when Invention Machine Corp. tested special version of software system TechOptimizer (now part of IHS GoldFire), which was able to combine different scientific effects in order to design technical system to perform function stated by human user. We asked very knowledgeable research engineers to run the software, while watching their reaction to inventive concepts, generated by A.I. system. Typical reactions: if new concepts were based on effects, known to engineers, they analyzed and discussed them; if there was one unknown effect, they still tried to understand the concept; but with two or more unfamiliar effects engineers usually ignored them without even trying to go into details. This problem is quite serious.

To increase chances of novel ideas acceptance we suggest to use technology shells as a format for description of future inventions.

5. Hybrid creativity as foundation of new civilization

Human civilization was born, when Sumerians invented external memory, i.e. writing. Five thousand years later we witness a very exiting phenomenon, what we believe is the birth of new civilization, in which creative artificial intelligence will co-exists with human intellectuals [11]. We think, that rapid increase of creative A.I. performance may reflect fundamental principle of the universe – unlimited expansion of intelligence and creativity.

The most interesting and at the same disturbing trend which will lead to drastic change in human life, is an exponential evolution of computer hardware, which opens great opportunities in writing creative software, capable of solving engineering and similar problems in non-stop mode, i.e. inventing future technological world.

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"HOW TO ADMINISTER TRIZ?" – EXPERIENCES IN INTRODUCING TRIZ

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Abstract

TRIZ is established in many large organisations as a key process to maintain the innovation engine. However, this hides the fact that to achieve this status it has taken time and special efforts. As in many initiatives there are the usual top-down and bottom-up approach, with most proponents agreeing on clear need of a top down approach.

The authors have had mixed experiences in introducing TRIZ in organisations. This paper is an attempt to identify key factors and correlate with leading indicators of an effective implementation of TRIZ. This is hoped to strengthen the theory for what could be an appropriate method to introduce and sustain TRIZ in organisations.

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Keywords: TRIZ introduction, implementation, Experiences

1. TRIZ implementation challenge.

1.1. Background

The success of pioneers in utilisation of TRIZ as an innovative tool is well publicised. TRIZ has helped these organisations to find a way to consistently deliver on innovation metrics. These organisations have institutionalised innovation by embedding the 'TRIZ way' of doing in their routine practices. They have also developed internal organisational structures to sustain the innovation engine.

How have these organisations reached this level? What were the challenges faced in the beginning, how have they overcome it? It is evident from their experiences that this has been achieved over many years of effort[1-3,6]. How did they sustain this interest in TRIZ?

We have in this paper tried to study the challenges faced by practitioners and have compared with our own experiences in approaching Indian firms planning to incorporate TRIZ in their innovation armoury.

1.2 What have others said about Challenges in implementation:

Literature on implementation of TRIZ in organisations [1-4] deal with the success achieved and description of the process followed. The narratives refer to in retrospect mainly describing the achievements made and existing status of the organisations with scanty,[5,6] publications on descriptions during the initial period when challenges would have been innumerable.

GE[1] has historically introduced TRIZ as a part of their Quality effort more specifically their DFSS team (Design for Six Sigma methodology). TRIZ was found beneficial in building alternate concepts and later the scope of application has widened. In retrospect GE has followed the process dictated by the change management process, starting with identification of the need followed by mobilizing commitment and lastly making the change last.

Adunka[2] have reported the implementation of TRIZ in Siemens automation. The introduction has been done with an eye on the outcome in a methodical manner with multiple training workshops concepts based on outcomes targeted. They have found great amount of initial success in the solutions obtained and a drastic increase in the innovations reported. The innovation has been institutionalised by setting up of academy with various training levels.

Jun et. al.[3] have explained the method followed in Samsung. The major difference in their implementation seems to be the focus provided by Samsung leadership to use TRIZ to become a leader from a traditional fast follower company. Large number of external experts inducted along with a clear direction for internal employees to independently handle TRIZ projects are the highlights of Samsung TRIZ story.

A study by Moehrle[5] indicates there is a method in how the various tools of TRIZ are utilised. to understand the usage of TRIZ. The authors have identified subsets in the TRIZ tools which users accept. This acceptance is based on user appetite and need for using TRIZ. These subsets require different level of understanding and pose different levels of difficulty to users.

Jirasek and Kulhavy[6] have studied the introduction of TRIZ in a mechanical engineering industry. The authors had a mixed response. TRIZ was found to be useful for assisting innovators find new ideas. Their study also showed that short trainings are found to be ineffective as it led to a mismatch of expectations with deliverables. They found there was a case for selecting only a handful of tools for training to meet expectations.

Victor Fey[7] in his keynote address has mentioned the challenges TRIZ has to overcome to "soar" rather than just "fly". Here Fey has bought out the special ability of TRIZ to solve difficult problems in the most effective way. However, to achieve this one needs to be specially disciplined in following the process laid out by TRIZ with no real short cuts. 'Complex', 'inessential' and 'undemocratic' are the three contrarian terms used by Fey to describe TRIZ to bring out the special nature of TRIZ implementation. In essence, Fey believes TRIZ cannot be a tool for mass implementation and will be a niche tool especially for the more challenging problems.

1.2 What Challenges do successful training program in general face:

Success of TRIZ training broadly would also face issues faced by any training program. The dynamics of a successful training program requires many elements in place. Calhoun et. al[8] have identified a model which captures 6 elements required for successful training. Coined as 6D the elements are:

D1 Define Business Outcomes, Any training program should cater to business objective to be identified by all.

D2 Design the *Complete* Experience. The training should also design the actions subsequent to the training so the participants are clear of the expectations and actions.

D3 Deliver for Application. True learning requires the participants to apply the learnings in their situation which needs to be monitored

D4 Drive Learning Transfer. The learnings have to be brought to the workplace situation for it to be the new normal.

D5 Deploy Performance Support. The organization should facilitate the deployment of the technique by supporting the participant and identifying accountabilities of key change agents and have timebound reviews.

D6 Document Results. Documenting the experiences of the learning helps the learning process to be identified.

2. Analysis:

We can summarise the main challenges for an appropriate TRIZ implementation as below.

The organisations are at different levels of their TRIZ journey. For organisations in the beginning the stage is identified as "Buy-In" where the organisation is in the process of identifying TRIZ as an engine for innovation. For organisations where the Leadership have identified with TRIZ the stage is called as "Institutionalisation". In both the stages the challenges faced are identified by 5 Main factors listed below.

Table1

Factors for implementing TRIZ implementation

Stage	Sr. No.	Main Factors	Sub factors	Author
Buy in	1	Management buy in	Setting Business Objectives, Internal champion	Jun[3], Calhoun[8], Jirasek[6],
	2	Proof Of Concept experience	Success stories, Team expertise.	Moehrle-[5]
Instituitionalisation	3	Management Support	Directions, Reviews.	Adunka[2], Jun[3]
	4	Process orientation	Performance support, Learning transfer	Gardner[1]. Calhoun[8], Adunka[2]
	5	Complexity	Subject matter knowledge, learning curve.	Moehrle[5], Jirasek[6]

The main stages could be associated with any new initiative. In TRIZ implementation the factors contributing to the success of the stage have elements which need special attention.

3. Our study:

The authors have been involved in the implementation of TRIZ in numerous organisations. These organisations belong to sectors like Engineering , Consumer goods, Auto and auto ancillaries, Electrical goods and services. For the sake of this study the authors identified 12 organisations in which TRIZ is being applied as a tool to enhance their innovation potential. These 12 were selected on the basis of the seriousness of the organisations in implementation.

These companies are in the process of implementation of TRIZ process and have invested anywhere between 6 months to 30 months in this method. Companies in the 'Buy-In' stage have invested 6 months to 2 years and companies in the 'Institutionalisation' stage have invested 3 to 5 years.

The 5 main Factors for TRIZ implementation identified from the above analysis are as below.

1. Management 'Buy-in' is essential to set a clear objective for the intervention and also help develop focus for the participants beyond the initial classroom training. Identification and effectiveness of an internal champion to keep the agenda alive is crucial.
2. POC Experience: POC is the step wherein the organisation and participants gain confidence in the 'suitability' of TRIZ. This is a tough call which is the first step where the organization gets a taste of what TRIZ is capable of. In most cases based on the outcome the buy-in takes place.
3. Management Support. Once having taken the step of deciding to use TRIZ, senior management sets the priority for the organization. Reviews and setting the process for the application of the learnings by senior management becomes important. The role of the internal champion is crucial.
4. Process orientation: For learning to be transferred and to get best results sticking to the process and building a process view of TRIZ is important.
5. Complexity : For more intransigent problems and better solutions there is a need to take up the more abstract parts of TRIZ which demand different expertise to be utilized. Complexity is mostly relevant in organizations which have reached a maturity in usage of TRIZ.

The organisations studied are in various stages of implementation hence what it is appropriate to identify and study the leading factors. We rated the organisations on these factors. For each of these organisations we also identified key leading indicators of success in implementation as below:

1. Quality of success stories.
2. No of projects implementing TRIZ.
3. Number of employees trained.

The factors and response were collected based on a survey with the clients. The responses were numerically converted as per Table2 given below:

Table 2

Explanation of Survey Factors and Response

	Factors and Response	Rating significance (0 -lowest and 10 highest)	
		0	10
Factors	Management 'Buy in	no buy in	complete Management buy in
	POC Experience.	No ideas	Breakthrough Ideas
	Management Support	No reviews	Regular reviews
	Process orientation	No adherance	strictly TRIZ method
	Complexity	"Simple' TRIZ tools	Use of level 3 professionals

Response	Quality of success story	No new ideas	Novel unthought of ideas
	TRIZ implementation in projects	No new projects	All projects using the TRIZ filter
	Employees trained	No new employees trained	All employees trained

The values of both the factors and response was represented as a single number by taking the average of all the factors and responses. Thus, evaluation of each client was represented by one factor and one response. Fig1 represents the factors and response of each of the clients as a scatter plot .

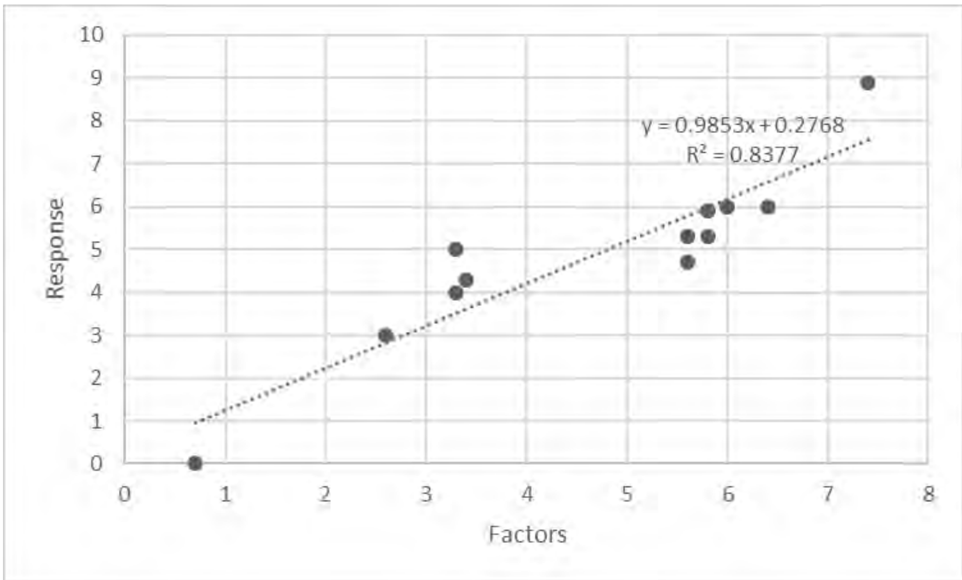

Fig 1: Correlation of the Factors and responses from TRIZ users

There is a strong correlation of the main factors identified with TRIZ implementation. The high value of the regression coefficient indicating significant amount of the variation in response is answered by the factors identified.

4. Conclusion

Successful TRIZ implementation can be decomposed into two components namely buying-in and effective institutionalization.

Senior Management buy in & support, Proof of Concept (POC) experience and process orientation are factors which play an important role in enhancing effectiveness of implementation.

Addressing complexity could play an important role in extracting maximum value from TRIZ. However, this requires a higher level of commitment from the stakeholders in the TRIZ process

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HOW THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ) CAN BE IMPLEMENTED TO AUTOMOTIVE INDUSTRY IN THE EXAMPLE OF JAGUAR LAND ROVER?

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Abstract

The aim of this article is to constitute methodology for the potential applications of TRIZ to automotive industry in the example of Jaguar Land Rover. This paper tries to identify and analyse requirements of application specific to company, potential financial and non-financial benefits could be achieved via implementation. That work also aims to provide alternative approaches for stakeholder integration & engagement and management strategy for required changes to ensure appropriation of methodology for future applications. With conducting interviews, analysing existing methodologies used by company and potential application of TRIZ intended to be evaluated in terms of, effectiveness and areas can be improved. Additionally, the article presents how TRIZ could improve level of innovation, design and development and how technological evolvement prediction could influence company strategy.

Keywords: TRIZ, Automotive, Implementation Strategy, Change Management

1. Introduction

Theory of Inventive Problem Solving (hereafter TRIZ) presents systematic problem-solving methodology with innovative outcomes [1]. The methodology constructed upon discerning systematically prospering and simple solutions or answers which lessens input required to come up with elegant, simple but vigorous solutions. By providing systematic approach which influence its users to think outside of box, TRIZ enable individuals to build their unique toolkit to problems to solve problems in their styles and accelerates problem solving for individuals and teams. However, TRIZ interpreted as a methodology which can only provide technical solutions to faced problems and its applications couldn't be expanded further areas. Some authors define reasons for that as TRIZ doesn't meet the expectations of users and doesn't have rich parents like kaizen or six-sigma [2]. The aim of the paper is mediating an implementation strategy for TRIZ in automotive applications and evaluating its effects on company strategy.

Jaguar Land Rover (hereafter JLR) is built around two iconic British automotive brands merged after Tata Motors acquisition from Ford. Land Rover is world's leading manufacturer of all-wheel drive vehicles in premium and Jaguar is one of the best brand for luxury sports saloon vehicles. JLR also is major investor in research, development and engineering for automotive industry in UK. JLR has two research and engineering design centres and four manufacturing plants in UK where company operates more than 100 countries worldwide. The company took number of awards recognizing and respecting diversity and inclusion journey. JLR's culture drives business excellence to achieve better efficiency, productivity and cost management. In order to achieve these aims, JLR gives great importance to innovation [3].

1.1. Research Methodology

Retro perspective approach preferred for obtaining information within literature and industry where that approach based on both colleting of past data for unit analysis and evaluating the impact of engagement. Phenomenon of interest selected as TRIZ and its industrial applications and stakeholders who will be most affected in the case of implementation identified as product development, human resources and strategy departments. Potential areas of concerns also prescribed as change implementation, effects of improvement effectiveness, project planning and company strategy. Total number of seven interviews completed with JLR employee working in various departments. In addition, an interview is conducted with a TRIZ expert who gives trainings in various continuous improvement methodologies and TRIZ to evaluate the validity and consistency of ideas where also valuable thoughts of expert tried to be taken. Interviews and company documents taken as primary source of information. Potential impact of study tried to be identified by evaluating various sources to find relevant information about phenomenon. Appraisal of impacts continued until impacts of study resulted gratifying predictions which would lead recommendations for future.

Inductive approach selected as methodological strategy in which theories proposed towards the end of research result of observations. Patterns of phenomenon tried to be utilised by using observations and explanation developments. By taking data sets as basis, patterns and relationships employed to reach conclusions in order to explain phenomena [4,5]. Explored patterns employed to address the research objective of paper which is “Promoting implementation strategy for potential application of TRIZ in automotive industry”. Inductive reasoning preferred to analyse process oriented questions. Academic articles, interview findings and analyse of internal documents compared to identify patterns. To settle baseline and gain understanding for potential application and its effects on company, literature review focused on TRIZ, change management, continuous improvement, project planning, problem solving, technological evolvement and its effects on company strategy

1.2. Literature Review

“Teorija Rezhenija Izobretatelskih Zadach” (TRIZ) developed by Genrich Altshuller and his team who studied 400,000 patents where they discovered regularities and basic patterns which governs creating new ideas and problem-solving process. That methodology regarded as beneficial for developing new systems and providing set of principles to system or technology evolution trends [6]. Objectives of TRIZ defined as cost reduction of manufacturing, product/process improvement, cost reduction by avoiding competitor patents, developing new core technologies and new concepts for existing product design. Parallel to these objectives, six directions of TRIZ identified as existing product improvement, new product development, manufacturing technology development, patent overcoming and new patent development, short/long term forecasting and scientific and research engineering [7].

Unlike various problem solving and continuous improvement methodologies, TRIZ helps to identify problems and propose direct solutions to problem by classifying and analysing root causes of problem. In shallowly, TRIZ methodology also could be expressed as, problem similar to mine could be already solved. Proposed direct solutions based on inventive principles, trends of technical evolution and standard solutions. In order to identify required improvements, TRIZ suggests problem need to be reduced to its essentials and need to be indicated in conceptual format. Later, problem could be matched with conceptual solutions. Finally, conceptual solutions could be transformed to factual and specific solution which address the original problem [8].

Although TRIZ tools doesn't present strict sequence for application, these tools could be categorised within five fields which are current state, resources, goals, intended state and transformation. Current state tools try to identify how current situation looks like, resource tools help to distinguish available resources in terms of both currently using ones and additionally available ones. Goals selection tools enable user to satisfy and ensure goals of the system. Intended state tools provide out view how future solution need to be look like. Transformation tools helps to identify required steps to transform current state to intended one [9].

Continuous improvement process aims to lead gradually developments to present capabilities. Some conjunct aims observed among different continuous improvement tools such as; satisfying customer needs, improved organisational performance and the absence of errors where quality improvement is also main concern [10]. Different to gradual developments, TRIZ can provide faster and effective solutions with its powerful tools such as engineering parameters, inventive principles and contradictions matrix [11]. In addition to solving existing problems, TRIZ could enable companies to develop new products and predict new markets with using forty inventive principles and eight trends of technical evolution. Furthermore, TRIZ could provide access to database of cause/effect built based on experiences from other companies and industries [12]. Predicting the direction of technological evolution and anticipating market trends enables company to form strong strategy. As stated in JLR's annual report, "Future success will be based on continuous process of anticipating new market trends". These trends are; tighter fuel economy relations and increased safety standards, increased demand for digitalisation of car, automobiles as all-purpose vehicles which requires flexibility of choice, increased cross- based comparison[13].

TRIZ often considered as set of tools which help designers to reduce trial and errors and in design and develop areas [14]. In addition, Spreafico and Russo implies that, TRIZ can be used in quality improvement and product or process innovation [15]. However, TRIZ methodology and applications being condemned in numerous dimensions. Inadequate specificity of TRIZ literature, lack of predominant modalities to present idea [16], word-centric structure which considered as hard to adapt for initiative and visual thinking styles, some tools considered as being too artificial [17], difficult fundamental principles and dissemination of theory [18]. Unfamiliarity, shortcoming of standards and lack of corporate sponsors can also be considered barriers against implementation [19]. The unfamiliarity of TRIZ could be eliminated by actualisation of theoretical phenomenon. Jirásek and Kulhavý states that, practically oriented trainings to create real life innovations could increase popularity by providing tangible outcomes [20].

Samsung Group is one of the early implementers of TRIZ. Between 1998-2004, company obtained 150 patents and made financial contribution around 250 million US dollar with TRIZ application. TRIZ activities were used for technology and product prediction. Company integrated TRIZ to improve process and products, reduce costs of manufacturing, design and develop future technologies. Unfamiliarity obstacle were tackled with getting successful results in real project with application of TRIZ methodology. Essential requirements of application specified as management support, public recognition, innovation network and including people with innovation experience. At beginning stage, management support considered as most important requirement where TRIZ was introduced company from top level including CEO. Including people with innovation experience and encouraging TRIZ activities by linking with promotion also contributed for easier and faster implementation. Employee motivated with successful outcomes of real project where TRIZ methodology is used. Samsung also holds TRIZ festival to create public recognition where successful projects were exhibited and awarded prizes. In addition, Samsung hired full-time TRIZ specialists in corporate technology operations division to get help employee with TRIZ in the areas of consulting, training, solving problems in projects and promoting in-company experts [21].

Firm's innovation capabilities can provide flexibility to adapt demanding and constantly changing requirements of industry by providing range of alternatives. Technological diversification enables companies to sustain business renovation and evolution of firm where patent portfolio could help company to achieve these. Technology could help prioritisation among various alternatives by providing alternatives to evaluate [22,23]. By providing range of possibilities, technology supports integral relation to company's strategical thinking where technological strategy need to be elaborated with planning and production to turn designed capability into saleable goods and services [24].

For smoother and effective implementation, related stakeholders need to feel themselves as part of process where asking employee opinion creates a feeling where these people consider themselves as a part of change. Requirements, outcomes and purposes of the change need to be well explained to convince stakeholders. Personal needs at different levels and initial plan need to be modified appropriately for better change management [25]. Tools and practices which are going to be applied during process need to be selected in complementary manner and these tools and practices need to be integrated with current practices. Also, the plan of implementation and how all steps fit together need to be constructed [26].

Management have great role at implementation of change where they could influence culture by controlling things to pay attention, measure and control. Furthermore, management also deliberate role modelling and coaching others to internalise desired values [27]. Management role need to be coaching their juniors to solve problem by themselves rather than delivering solutions to problem [28]. Top management behaviour ought to be translating implementation process and goals to way stakeholders can understand where that language should be refrained from complex or theoretical perspective [29]. On that way, company culture can assist managers to overcome prejudges if it emphasizes being open to different opinions and sharing values [30].

2. Analysis and Results

Following chapter compares primary data obtained from interviews and existing validities of literature. These separate information sources are utilised to identify financial and non-financial benefits of application, constructing change management strategy, evaluate potential effects on company and develop implementation strategy for potential TRIZ application specific to company.

2.1. Analysis

Continuous improvement tools are used in production and service industries in the areas of process monitoring, production control, preventative maintenance for production and optimisation & simulation for service industries. However, continuous improvement tools being criticised generating rigidity and over focusing on solving problems without innovation. Interviewees contribute these shortages by stating these tools are not sufficient to contribute innovation, being ineffective for complex problems and over focusing on production. One interviewee contributes, strict tools unable to contribute innovation where flexibility is necessary. Most of interviewee agrees on problems commonly repeat itself and they develop similar solutions to solve these problems.

JLR practices Tata Business Excellence Model (hereafter TBEM) to execute excellence activities in company. TBEM provides opportunity to align all range of stakeholders and bits of supply chain to practice organisation capabilities improvement and effectiveness. In order to strengthen excellence in manufacturing JLR use wide range of problem solving and continuous improvement tools used in company such as Kaizen, Lean, Six-Sigma, FMEA etc. Furthermore, JLR also formed unique tools specific to company such as Concern & Countermeasure tools to classify required actions or containments for analysed concerns and countermeasures and Practical Problem Solving tool which incorporate different features within one tool. Although these tools provide beneficial outcomes process improvements and daily problems they could be criticised not being innovative. TRIZ could help company to develop inventive solutions and predict evolution of technology which can help company to developing future products. Solutions or lessons learned databases enable users to learn from previous problems which could minimise required time for solution of repeating problems. Only two interviewees use these databases to find solutions for repeating problems. TRIZ could be beneficial to tackle these deficiencies where continuous improvement methodologies couldn't lead innovation.

Uncovered areas identified as:

- Current application of methodologies won't provide analysis of technological trends
- Used tools enable to identify root causes of problem but they couldn't offer direct solutions
- These tools solve problems exclusive of leading innovation
- Similar problems database couldn't efficiently use

JLR identifies core values of company as excellence, integrity, pioneering, unity and responsibility. Specifically, unity and excellence are directly related with continuous improvement where unity described as investing people by providing continuous training and excellence defined as aiming to achieve highest standards of quality. Innovation enables company to achieve pioneering to develop customer insight and innovative solutions. Trends influencing automotive industry described by JLR as; increased demand for digitalisation of products, tighter fuel economy and safety standards, flexibility of chooses in products, increased cross-band price comparison, increased usage of digital resources on purchasing decisions and threat of new entrants to industry especially technology giants. JLR considers innovation as essential to conform the requirements of these trends. Almost all interviewee considers innovation is essential for JLR. Their opinions converge on innovation improves efficiency, current abilities, reduces necessary requirements and sustain their competitive advantages.

Most important aim of continuous improvement activities is reducing cost of manufacturing. TRIZ is differentiated with continuous improvement methodologies providing innovation in addition to leading cost reduction. Continuous improvement tools mostly focused on process improvements where it couldn't contribute product improvement. Parallelly, one interviewee contributes, application of continuous improvement can only provide solutions for daily problems. Another interviewee builds on that, strict roadmaps of these methodologies causes inability to contribute innovation. Existing product dimensions and manufacturing technology directions of TRIZ enables to achieve the aims of continuous improvement tools. In addition, development of future technologies, forecasting of new concepts, avoiding competitor and discovering new patent objectives of TRIZ are related with innovation. Furthermore, scientific and research engineering, patent overcoming and development and short or long-term forecasting directions enable TRIZ to contribute innovation where it is considered as essential for JLR.

Also, trends for technological evolution and trends enable designers to explore areas for value generation and evolutionary limits for design.

By providing relatively flexible structure compared with other methodologies, TRIZ can help to improve existing innovation capabilities where different users can develop unique toolset specified for different problems with combination of different tools. TRIZ instructor interviewee contributes as, JLR could benefit 40 IP's and contradiction matrix detailed design and evolutionary trends in product strategy. However, there doesn't exist formal TRIZ training in JLR as interviewee indicates.

TRIZ also can provide first mover advantages and lead business strategy to blue oceans where lower competition exists with prediction of technological evolution and trends. Through these, JLR could strengthen their pioneer reputation which parallel strategical aims of company. First mover advantages can be enlarged as gaining access to unique customer and sale channels and defining standards for technology where late movers need to conform. Furthermore, company could analyse substitute products which could regarded as threat for existing products. In the example of evolvement of photographic film to digital photography could be predicted beforehand where hybrid or electric car technologies could be regarded in same manner.

2.2. Results and Implementation Strategy

Continuous improvement activities used in JLR mainly focuses on process improvement to improve efficiency of manufacturing operations. However, JLR regards innovation is essential for their products. Advertising innovation capacities of TRIZ contribute to took employee interest and raise popularity of TRIZ within firm. Most of the interviewee express their main motivation for continuous improvement methodologies as self-improvement opportunities. Therefore, employee motivation could be achieved self-improvement opportunities of methodology are well advertised. In addition, one interviewee working on quality department explained as, continuous improvement methodologies help in daily work they done. Process innovation opportunities took interest of employee working on manufacturing operations where employee working in design and development departments could be uninterested with continuous improvement methodologies if they consider these methodologies wouldn't help in their daily work. However, product improvement focus of TRIZ could take interest of employee working in design and development departments. By providing future trends of technology, evolutionary trends tools can help designers and developers to develop their work a step further. Also, evolutionary trends enable these people to identify evolutionary limits of design and areas for value generation. By providing future state of product, evolutionary limits could be beneficial to make selection between alternatives. Continuous improvement activities criticised for tightly structured methodology where it could limit innovation where flexible of TRIZ structure with wide range of tools can encourage employee to use that methodology.

Improved innovation abilities provided by TRIZ can reduce requirement of externally sourced technologies and improve the patent portfolio. As one interviewee contributes, evolutionary trends would be beneficial to guide product strategy and road mapping. There exist fixed costs on research and development activities where these costs would be harm the profitability of development activities if managed inadequately. Therefore, technological development activities need to be aligned with planning and production aims to ensure these capabilities transformed into saleable goods and service. In other words, technology development activities don't guide profitability where not all technological change is strategically beneficial.

TRIZ could be presented to JLR with collaboration of other tools to reach employee. These collaborations can also raise effectiveness of usage and even lead company to build their unique tools. DFMA can help to evaluate and analyse existing design where TRIZ assists to create innovative design solutions. Likewise, QFD can transform customer requirements to engineering parameters and expose negative relations in the form of contradictions where TRIZ can easily eliminate. QFD and VoC can also help to understand customer needs where TRIZ can provide innovative solutions to identified areas. In the same manner, Lean and Six-Sigma can be used to identify trade off solutions where TRIZ can eliminate these contradictions. That strategy would be considered as limiting TRIZ application but it can beneficial in the initialisation of application and raises awareness.

Foundation of innovation network is also essential for implementation where that network would be beneficial in designing and managing necessary activities for training, assistance and guidance for projects. Furthermore, full time specialist would be beneficial at initiation stage by helping employee in consulting, training and solving problems in application where their experience and skills enable smoother and more effective implementation. For guiding the projects in departments, TRIZ teams could be formed in each department. These teams can be supported by TRIZ specialists in the areas of training, consulting and solving problems in application of projects. TRIZ teams can take the workload of TRIZ specialists where employee can ask the guidance and help TRIZ teams first where simpler problems wouldn't take time of specialists. Forming these teams with members who previously had innovation experience can improve the efficiency of implementation where these people already understood innovation activities and they can provide more realistic analysis on what can be achieved or not. TRIZ specialists and TRIZ teams can provide mutual benefits for each other where TRIZ teams decrease workload of specialists and TRIZ team members provide insights and realistic feedback to specialist for successful implementation. Members of TRIZ teams can be considered as champions who provide guidance and assistance and TRIZ specialists could be evaluated as technical experts about methodology.

Intensity and content of training also crucial for effective implementation. There could be two levels of training which are basic and advanced levels. Content of basic training is developing basic awareness and education of elementary tools. That program enables participants to apply simple techniques to solve their problems. On the other hand, aim of advanced training is raising employee for internal TRIZ organisation levels such as TRIZ teams or specialists in order to eliminate the level of external support. Participants would be educated for more capable tools and complete their projects which based form their daily problems can be completed in the guidance of TRIZ specialists or TRIZ teams. In the example of JLR, basic training can be provided optionally and successful participants could be offered for advanced trainings to raise participants for TRIZ teams. In addition, content of the training need to be focused on actual technical problems employee faced which could improve employee motivation and raise interest against methodology. TRIZ is stereotyped as complex methodology where solving daily problems as examples and simplifying the training content can help to overcome these problems.

Incentivisation of training or successful projects wouldn't preferred in JLR to build motivation. Employee motivated to improvement methodologies by emphasizing self-improvement opportunities or providing promotion opportunities. Same preference can be used for TRIZ by underlining self-development opportunities and linking promotion or getting higher positions in hierarchy could be used to motivate employee for TRIZ activities. Also, creating opportunities for blue collar to promote in hierarchy can be used for employee motivation where their specific hands on knowledge could be merged with TRIZ to create innovative solutions.

3. Conclusions

By conducting interviews with JLR employee and analysing existing methodologies used in company, implementation strategy tried to be constructed for potential TRIZ application to JLR.

Interviews had been conducted with JLR employee from Human Resources, Quality, Strategy, Product Design, Research and Development departments and one training expert who gives various improvement methodologies training for companies including JLR. The content of the interviews focused on the areas of current awareness of TRIZ and other improvement methodologies within company, advantages and disadvantages of these methodologies, how far individuals are motivated for these methodologies, what is the importance of corporate sponsors with recognition of methodology, what are the reactions of individual against beneficial features of TRIZ. Literature review focused in the areas of change management, innovation and knowledge management, employee motivation, company strategy and TRIZ. Suggested implementation strategy enable company to utilize innovation focus and prediction of technological evolution of TRIZ which comprises uncovered areas of application of current tools used in JLR. Findings of the work could be generalised to automotive industry by evaluating employee profile, company structure and culture, innovation and knowledge management strategy, technology strategy, current improvement methodologies and their potential effects of implementation specific to company.

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HYBRIDIZATION OF DFSS- AND TRIZ-MODELING METHODS WITHIN AN INNOVATION ORIENTED DFSS-FRAMEWORK

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Abstract

DFSS – Design for Six Sigma is one of the most popular methodology for designing robust products. Robust products are characterized by small variations of output attributes of parts and systems in production and use, even if input parameters and confounding factors may vary. DFSS usually is a framework of different methods, structured in distinct project phases – there are several existing frameworks with specific, e.g. abbreviated DMADV, DCOV, DICOV, DIDOV etc. TRIZ tools and methods have been included in DFSS phase frameworks by many users, because they enhance traditional DFSS toolsets through their innovative power.

In this article further development of advantageous addition of TRIZ to DFSS methods is described. The works focus the Define- and Identify-phase, which are the first two phases in a DFSS DIDOV-framework. In these phases several modeling methods usually are part of the toolset. After first simple additions of TRIZ methods to the toolset in further development similarities between the used DFSS and TRIZ modelling methods have been identified. The hybridiziation of the modeling methods leads to integrated modeling notations and rules that incorporate both, the characteristics of the original DFSS modelling methods as well as the characteristics of the appropriate TRIZ modeling methods. The article describes the methodological fitting of the corresponding methods (e.g. of the so called boundary diagram with the TRIZ function analysis), the hybridization approach used so far (e.g. crossover of notation and rules) with examples as well as a critical empirical evaluation of the outlined hybrid methods.

Keywords: TRIZ, DFSS, Design for Six Sigma, modeling, robust design, robust products, hybridization, function analysis, boundary diagram, problem formulation

1. TRIZ and DFSS – together towards robust innovation

DFSS – Design for Six Sigma is “a disciplined process that provides the user with a structured methodology for the efficient commercialization of new products, processes and services” [1]. Actually it is one of the most common methodological roadmaps to develop efficient and robust products and processes in a short time [2].

TRIZ – the theory of inventive problem solving – comprises many methods and tools for creating inventive problem solutions, based on the research and the insights of Genrich Altshuller (see e.g. [3], [4]) and many other practitioners and scientists, that used, enlarged or specified the methodological base of TRIZ. Because of the similarities of the goals of both methodologies, today many DFSS-trainings encompass also TRIZ-tools, because the original toolset focusses more on the fact of robustness than on innovation. So TRIZ-methods and –tools tend to be a good fitting enrichment for the DFSS-process. This observation is widespread and many authors already described their approaches to implement TRIZ-tools or –methods into DFSS-processes (see e.g. [5]-[10], [22-23]).

In contrast to the DMAIC-cycle usually used in SixSigma-projects, in DFSS there is not just one phase-cycle model. One can find different – but similar – DFSS phase-models all, e.g. DMADV (Define, Measure, Analyze, Design, Verify), DCOV (Design, Characterize, Optimize, Verify), ICOV (Identify, Characterize, Optimize, Validate), DIDOV (Define, Identify, Design, Optimize, Validate) (see e.g. [1], [2], [11], [12]). Even if all this phase models have different names and/or number of phases, they all share the same approach and the toolsets spread over the various phases are very similar. So it's very natural, to insert TRIZ-tools and methods in DFSS, where the system of interest is designed in concrete terms i.e. where the system parameters are specified.

This article describes the integration of TRIZ to DFSS-processes in very early stages. So the impact of using it at this stages is bigger and leads to more extensive structural or functional changes than usually results from using TRIZ in later stages. So the following explanation of integrating TRIZ modeling methods to the DFSS-process doesn't show new TRIZ tools – but it offers a dramatic increase of the innovation performance of the DFSS-process. Because of the used similarities of modeling methods, this happens in a way, which is not strange for experienced DFSS-users.

2. TRIZ-function analysis enriches the DFSS-boundary diagram

In early stages of a DFSS-project, a boundary diagram is used to set the boundaries for the project and to illustrate different system components, interfaces to components outside the system and different connections between components, e.g. physical connections, transmission of electrical energy, transmission of mechanical energy, transmission of material, transmission of information and others (see e.g. [11], [12]).

Besides requirements engineering tools the boundary diagram is one of most common and important tools in DFSS projects, because it sets up the base for the system architecture. While developing the boundary diagram many decisions regarding the system design are made – but the diagram is just a descriptive tool, documenting the structure and dependencies of systems components.

The boundary diagram usually is used in very early stages of the DFSS-process – e.g. in the Define-phase of a DIDOV-cycle or in the Measure-phase of a DMADV-cycle [11]. It is used to identify the components, interfaces and interconnections – but at the same time, all these information is fixed right away: e.g. it's not very likely, that the number of components fixed in the boundary diagram maybe changed later. TRIZ-function analysis is a very powerful tool, to improve the system (e.g. using trimming and value-analysis). But in many DFSS-processes it's not easy to insert a completely separate new tool – and besides that, working steps creating a boundary diagram are very synergetic with working steps to create a TRIZ-function analysis.

Considering psychological inertia, the boundary diagram prevents more radical and maybe innovative ideas. On the one hand this keeps the DFSS-process straight on the other hand it prevents radical innovation that might be found in the project. This contradiction can be solved by separation in structure: instead of the boundary diagram as is, it is used in a second step as base for a TRIZ-function analysis. This may lead (e.g. because of trimming, working with insufficient or excessive functions) to a new model, that can be easily transformed back to an improved and maybe much more innovative DFSS-boundary diagram, see fig.1. This illustration follows the principle of abstraction–solution–specialisation, which is used to explain the working with many TRIZ-tools since many years (see e.g. [13]).

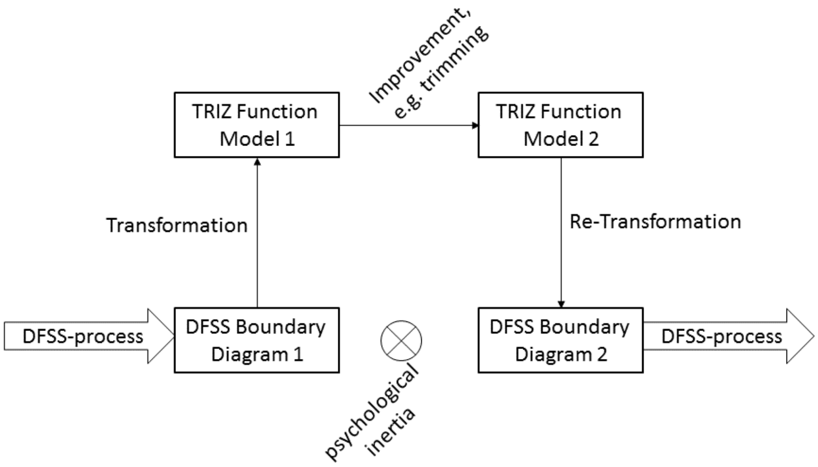

Fig. 1. Creating a better boundary diagram

Since the creation of the boundary diagram (see e.g. [11], [14]) and the improvement of a TRIZ function model are widely known and described in depth (see e.g. [15]), the transformation and re-transformation are the only missing elements to realize this approach.

Fig. 2 shows roughly a DFSS boundary diagram of a fuel cell drive unit concept for a vehicle. To transform it to a TRIZ-function model, a set of transformation rules was developed.

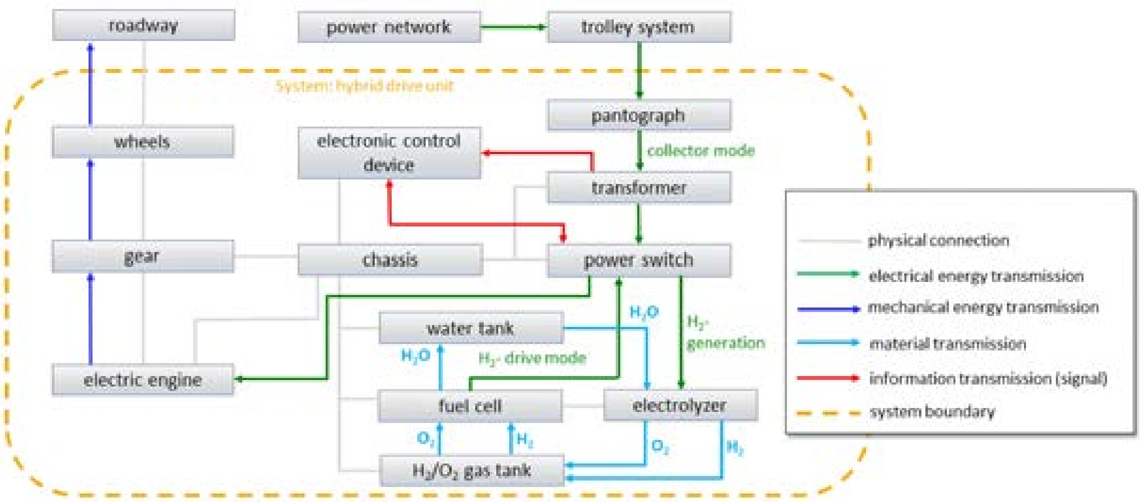

Fig. 2. DFSS-boundary diagram (example: drive unit)

Set of transformation rules:

- Identify the target component and set the system boundary according to the boundary diagram
- Transform each connection into a function – use active verbs and remember, that a function changes or sustains a parameter value of the object of the function
- Check the direction of the function – it may be equal or opposite to the arrow in the boundary diagram
- Evaluate the function designating it as normal, insufficient or excessive
- If there are more connections between two components, maintain each single connection as one function – don't merge various connections to one function

This leads to the TRIZ-function model shown in fig. 3.

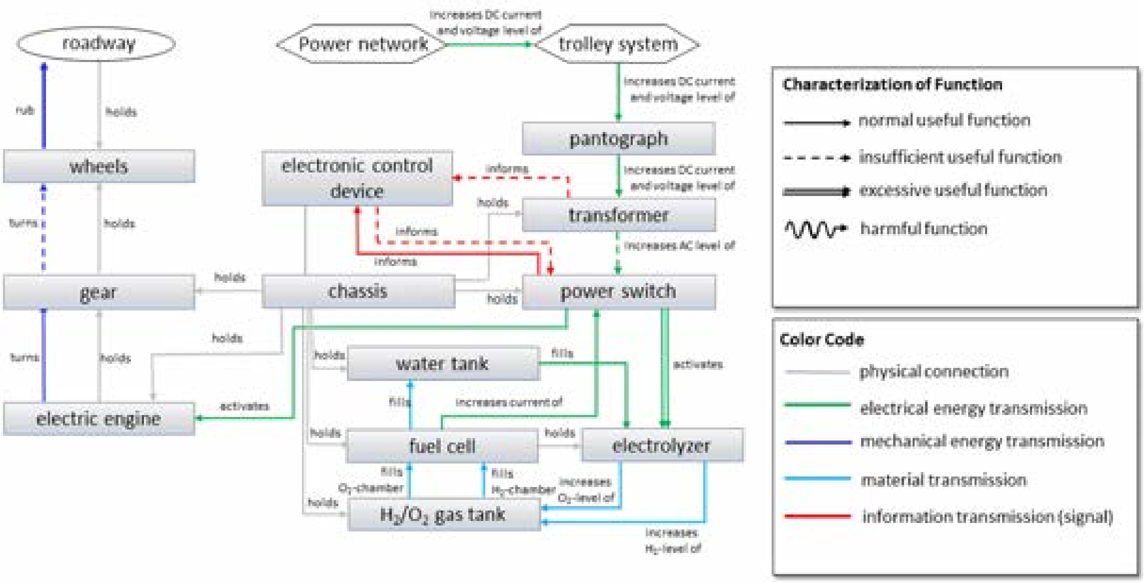

Fig. 3. TRIZ-function model after transformation (example: drive unit)

For the re-transformation the rules mentioned above are just used in the opposite direction. For this reason we will not show an explicit description of the re-transformation.

3. TRIZ-problem formulation enriches the DFSS-function decomposition

In the same way, the TRIZ-based problem formulation can be used to add innovative power to the DFSS modeling of functions. This modeling, also known as functional decomposition, is implemented mostly in early DFSS stages - e.g. in the Identify-stage of the DIDOV cycle and the Analzye-stage of the DMADV cycle (see e.g. [11], [16], [17]).

The DFSS-function decomposition illustrates the functional cause-effect-chain of the system. It provides the base for the mathematical modelling of the system in later DFSS project stages. The DFSS approach for developing the model bears the risks of missing improvement and overseeing potential malfunctions. Very often the found solutions are very robust, but also very complex and not very innovative. The DFSS-function decomposition is an irreplaceable component of the DFSS approach. The hybridizing with the TRIZ-problem formulation offers great synergies and allows further opportunities for the innovative functional improvement of the product.

The functional analysis in DFSS leads to a detailed framework about the useful functions of the system and can be found in DFSS-toolsets in different kinds – e.g. in hierarchical structures or cause-and-effect-chains (see e.g. [11], [12], [16]). Especially in the latter case, there is another opportunity, to add creative thinking with TRIZ modeling tools to the DFSS approach. Like shown above, now the TRIZ-based problem formulation can be used to improve the DFSS-based functional analysis dramatically.

Adding the step, to transfer the DFSS-model to a cause-and-effect-chain modeled according to the problem formulation rules, the resulting model offers the usage of many TRIZ-tools very easily and may lead to incremental or even radical improvements. Without this step, in ordinary DFSS-processes, the function decomposition very often has not a very creative character but is more or less just exploring and describing existing thoughts. So without the TRIZ-based indirect route, psychological inertia prevents innovative ideas at this point, see fig. 3.

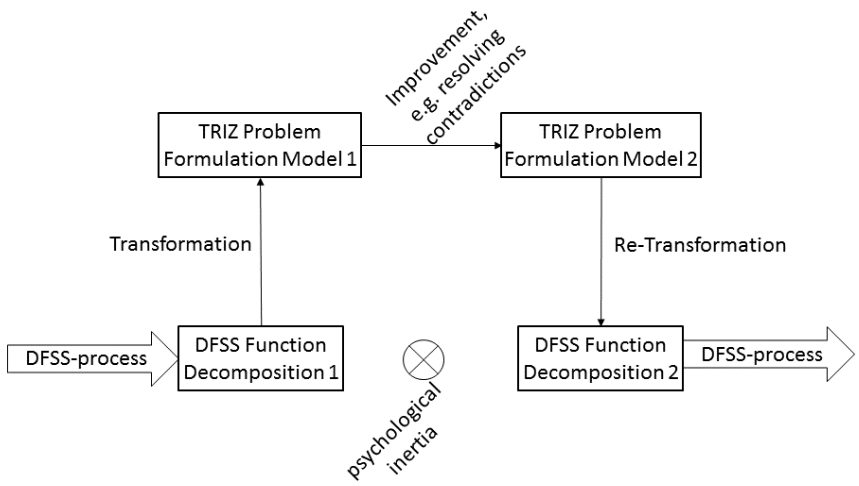

Fig. 4. Creating a better DFSS-function decomposition

Since the creation of the DFSS function decomposition (see e.g. [11], [16]) and the TRIZ-based problem formulation (see e.g. [18], [19], [20]) are widely known and described in depth, the transformation and re-transformation are the only missing elements to realize this approach.

Fig. 5 roughly shows an extract of the DFSS-function decomposition of a fuel cell drive unit concept for a vehicle. To transform it to a model according to the TRIZ problem formulation, a set of transformation rules was developed.

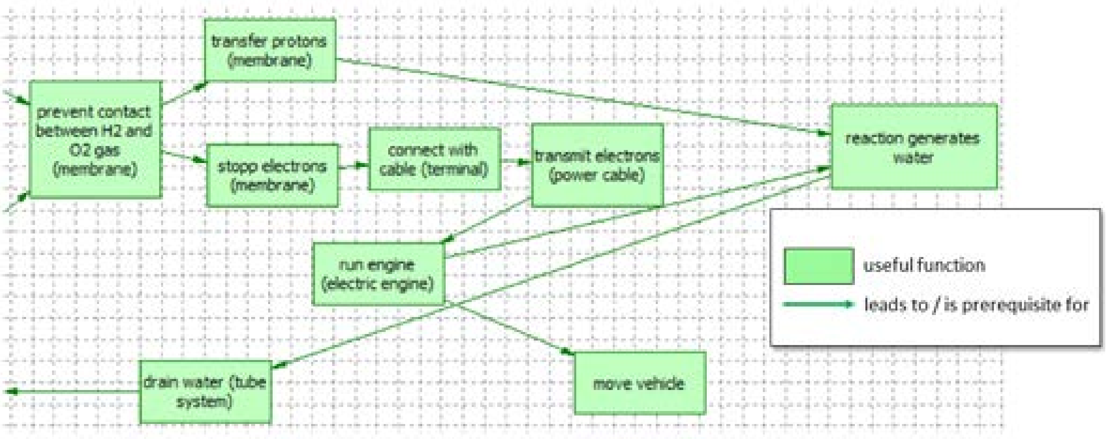

Fig. 5. Extract of an DFSS-function decomposition (example: drive unit)

Set of transformation rules:

- The DFSS-model contains only useful functions – now add the harmful functions
- The DFSS-model contains only "leads to"-connections – now add also "eliminate/prevents"-connections
- Identify the contradictions in the model
- Formulate the "directions for innovation", according to the problem formulation approach for contradictions, useful functions and harmful functions

This leads to the cause-and-effect-chain-model for the problem formulation shown in fig. 6 and a list of "directions for innovation", that can be treated as a to-do-list for innovative improvement of the system.

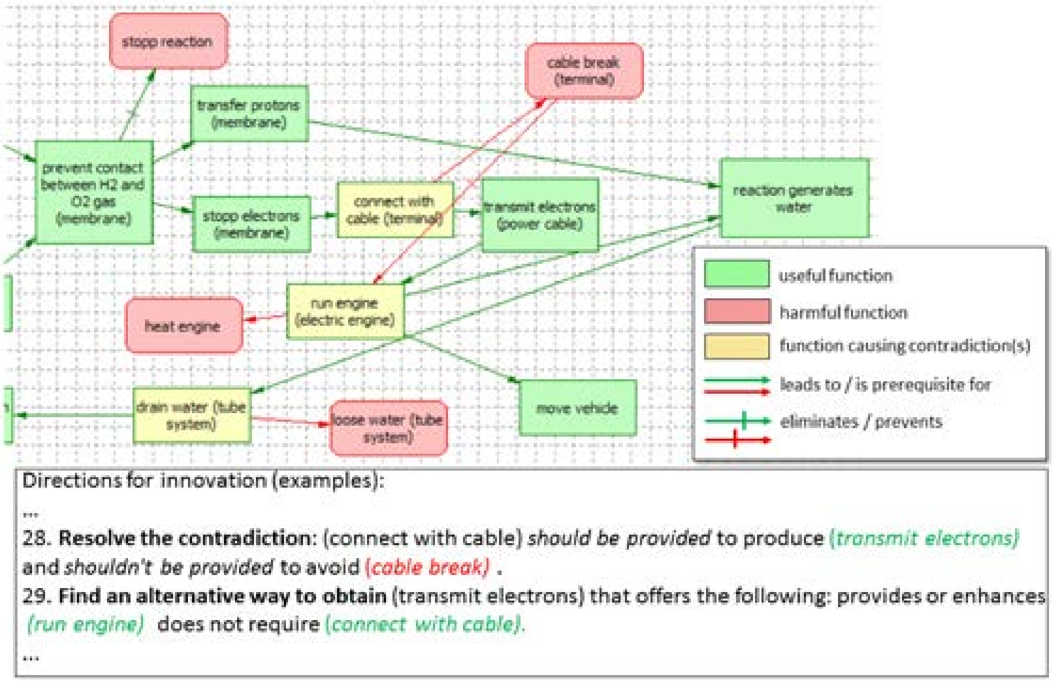

Fig. 6. Extract of the TRIZ-based problem formulation (example: drive unit)

After implementing the improvement ideas into the model, the new model is ready to be transformed back to the DFSS-model for function decomposition. The rules mentioned above are just used in the opposite direction and the list of directions for invention is stored for maybe later re-usage, if applicable. For this reason we will not show an explicit description of the re-transformation.

4. Initial experiences applying the hybrid modeling in practice

Many companies developed their own repertoires of DFSS methods and integrated DFSS approaches in their development processes. In between also much customers (e.g in the automotive sector) call their suppliers for using DFSS to create robust components and products. Because the methods are set so far, there is a reluctance to add new methods to the defined DFSS approaches. The practical work of the authors shows, that the hybridization is a very comfortable and efficient way to enclose important TRIZ knowledge in an already set methodical environment. Furthermore essential TRIZ elements can be brought to a wide range of designers and developers without separate TRIZ education.

Continental Automotive conducted a pilot project in its “advanced development” in the field of turbochargers. At the locations Grünstadt and Regensburg in Germany, the usage of the internal defined DFSS-process is obligatory. So boundary diagrams and DFSS-functional decompositions are mandatory elements of the development processes. The synergies described in this paper have been verified on an empirical basis in the pilot project. The project team used the hybrid modelling and on this way the developers learned and applied TRIZ-based value-analysis, trimming and working with contradictions. For reason of confidentiality further details of the project will not be mentioned here.

The authors also use these approaches in their DFSS-classes and –trainings. It might be adapted in some ways, e.g. other TRIZ-based modeling procedures may also be used, if the users prefer it (e.g. RCA+, see [21]) – in such cases, the transformation and re-transformation rules have to be adapted. In practice, not in every DFSS-process one or both of the creative circumventions may have to be taken. It’s up to the responsibility of the company or the project leader to decide, if the approaches described are embedded to the DFSS-process for every project or if there are decision structures to decide if they are used or not in a specific case.

5. Conclusion

DFSS-processes are todays standard in many R&D-departments. There are many approaches, to enrich the DFSS-process with more creative and innovation-fostering elements. The shown approaches do not create new TRIZ-tools for that reason but implement very well known modeling tools to DFSS-process in a way, that has three big benefits: First, this kind of implementation allows to circumvent psychological inertia that might be found in the many times repeated routine of processing of DFSS-modeling tools. Second, the way of implementation needs not much new methodological knowledge and experience – besides the well known procedures in DFSS and TRIZ, just a few transformation and re-transformation rules are necessary. Third, even if experienced DFSS-users don’t have to change a lot in their routine processes, this kind of implementing TRIZ enables them to realize incremental and radical improvements. The unity of the DFSS- and the TRIZ-modeling method incl. the transformation and re-transformation can find their place as a hybrid-method in DFSS-processes.

This approach of hybridize the modeling methods of TRIZ and DFSS doesn’t develop new TRIZ tools, but it helps finding ways for existing TRIZ knowledge being easily applied by a larger audience.

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Depictions for figures 5 and 6 have been made using the IWB®-software.

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INCREASED ADDRESSING OF HUMAN SENSES AS A TREND

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Abstract

TRIZ has become in the recent years a leading methodology for inventive problem solving for engineering systems. Samsung for example claims that TRIZ helped them to speed up development of their Smart Phone Galaxy so that they could compete the Apple technology. One of the key results of TRIZ founder, Gendrich Altshuller's research, is the definition of the "Laws of Engineering Systems Evolution". These Trends have proven their correctness over decades in the technical and non-technical environment.

This paper suggests adding another viewpoint to the trends by not only considering the development of technical systems themselves in a technical environment, but by focusing on the interaction of a technical system with users and the resulting requirements and development directions. The novelty is to propose an algorithm to fast identify gaps of a product addressing the human senses and therefore being able to foresee product evolution. By defining a systematic approach, the development directions for products interacting with humans gets predictable.

Keywords: TRIZ, trend analysis, TESE, 5 human senses, dynamization, trend of coordination, product development prediction. MPV, extension of human senses

1. General characteristic of research

The development of the "Laws of Engineering System Evolution" is one of the fundamentals of Altshuller's TRIZ Methodology. Engineering Systems (ES) usually do not exist for their own purpose. They in fact address human beings and serve them (one way or the other). Of course, the level of interacting with a human being is different. For example, fishing lures are primarily designed to address the senses of a fish, but still a person will touch it, mount it on the fishing rod, see it, etc. Many other systems will have a limited interaction with humans, but during mounting, operation and dismantling, at some point most ES will get in touch with a human being (unless it is a pure Machine to machine systems M2M). This paper deals with ES that are designed to have an interaction with persons.

Following this view, the human being is the super system and even the target of the technical system. The interaction between both is done by the senses of the human being. Interpreting this with the trend of "increased coordination", engineering systems evolve by increased addressing of human senses.

2. Relevance of the topic of research

Trends are the foundation of TRIZ. Today's technology is more and more customer-focused and related to their needs. Alexander Lyubomirskiy has shown in his research that there is a trend of "coordination of images". This trend focusses on the visual sense of a human being. My study suggests expanding this approach to all human senses like auditory, kinesthetic, gustatory and olfactory. With this the complete human interface with technology and the world is addressed.

3. Goals and tasks of research

During the research, it became evident that considering the interaction between a product and its user - a human being - can lead to a forecasting and prediction of an engineering system evolution that is designed to interact with humans. A simplified algorithm has been developed which makes it possible to identify gaps of a system related to the addressing of the human senses, thereby pointing out opportunities for further development and evolution. This paper describes the development of this simplified algorithm and discusses the systematic approach to this evolution.

4. Scientific novelty of research

The trends identified in TRIZ up to now mainly focus on the development of the technical system itself. Gen3Partners has shown how the value of a system must be taken into consideration much more in today's world. The trend of image coordination was a first step towards not only considering the value of a system to the user but to define the way that they are interacting. The proposed trend expands this idea to the full set of available senses of a human being. However, one can even think of other senses, e.g. of animal, if the system is designed to interact with the latter.

5. Practical significance of research

The trend suggested is the "Trend of increased addressing of human senses". It states that engineering systems that are designed to have an interface with a human being evolve to address more and more senses over time, starting form one sense, dynamizing it and / or adding other senses. The following figure shows the relation between the addressing of senses. The major ones are the visual and the auditory sense. They are also related to a far distance approach. The source / object of consideration can be at a distance that is greater than the human action range. The three other senses are kinesthetic, olfactory and gustatory. They are also near distance senses, where olfactory can as well act over a longer distance (Fig.1).

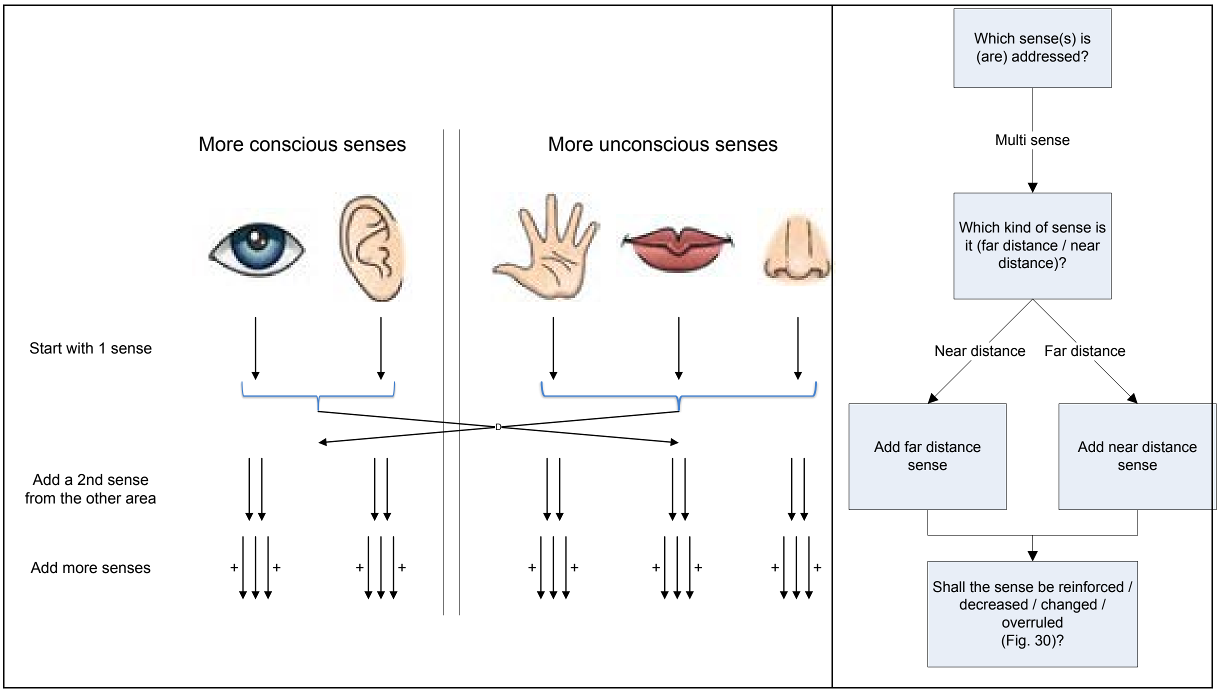

Fig. 1: Development of addressing human senses

A system addressing one sense (near or far) will strive to add a sense from the other cluster (far or near). This leads to higher general awareness and influence. Of course, the sense itself can be dynamized as well. The next step is to add another sense to deepen the effect and so on. A flow chart on how this can be written in form of a generic algorithm is developed (Fig. 2)

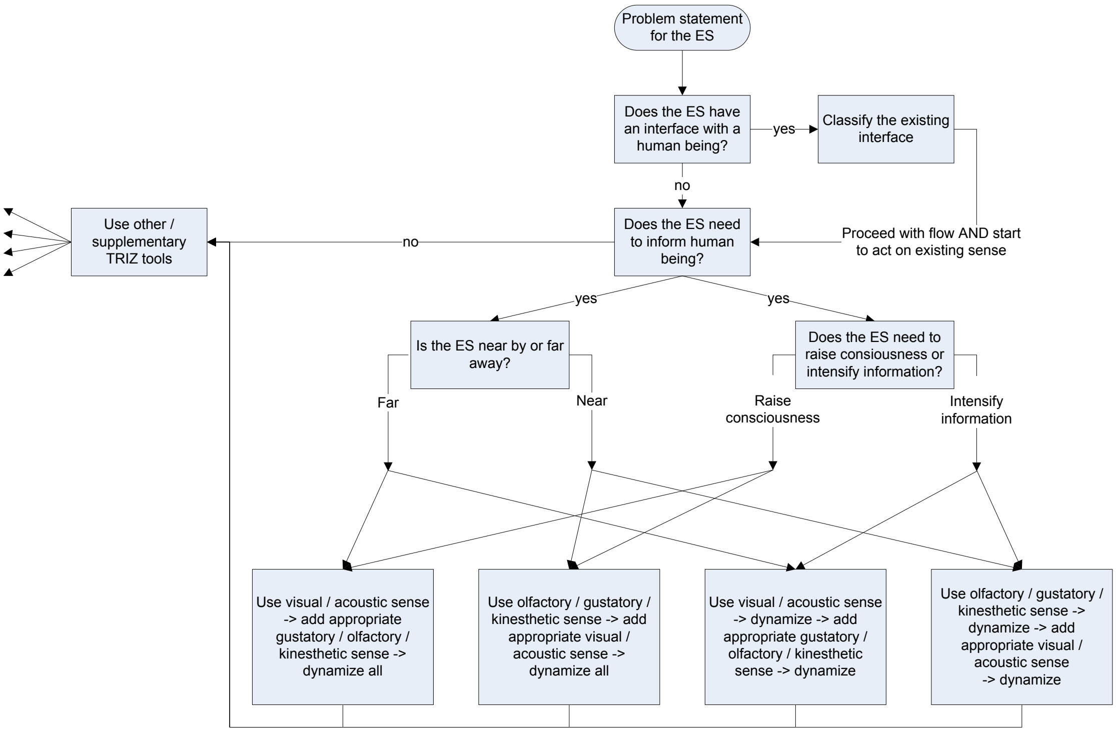

Fig. 2: Flow chart for addressing human senses

When working on an innovation one of the first questions that could be asked is, whether the problem has to do with addressing human senses. If one or several senses are addressed they must be identified. In the following process, they must be addressed first. Even if no sense is addressed, the need to do so must be identified. If there is no need proceed with other / supplementary TRIZ tools (not part of this thesis).

If one / multi senses need(s) to be addressed, two questions must be asked in parallel: to which category does / do the sense(s) belong: near / far and what shall be achieved: intensifying the information or raise consciousness? Intensifying the information means that the transfer is insufficient, but has already reached consciousness. Here the first action to take is dynamizing the existing sense and adding appropriate other ones, especially from the adjacent category, to get extended access to the brain. For raising consciousness, the near senses are generally better suited. So start with them and complete this sense by one out of the far sense category first. Then start to dynamize.

The suggested algorithm has been applied on several engineering systems from which 3 are presented in this paper: Elevator controls (buttons), candles and birthday cards.

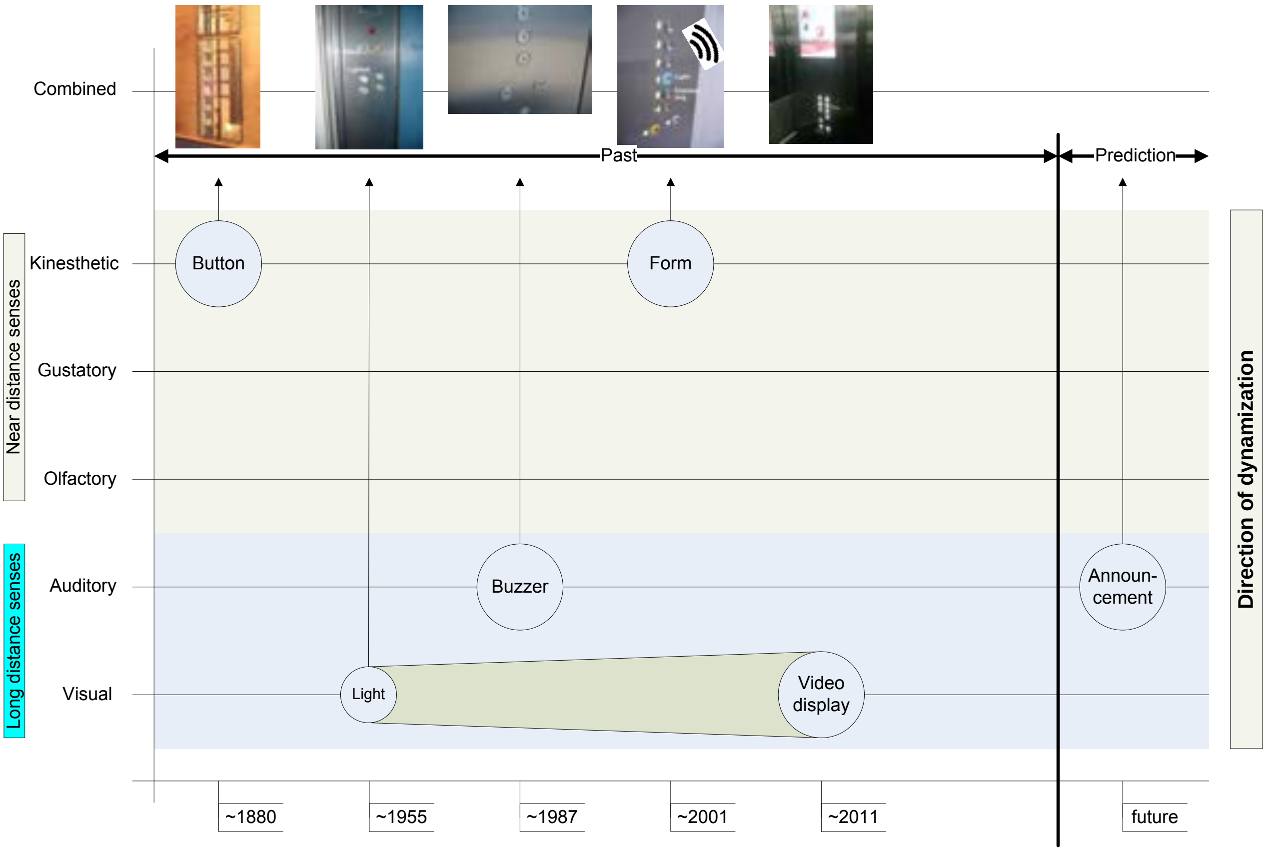

Fig. 3: Application of the algorithm to the engineering system “elevator”

Figure 3 shows the analysis for the elevator controls (push buttons). On the y-axis, the different senses are displayed. In the lower part the far distance senses are mentioned, on the upper bar the short distance senses are displayed. The x-axis represents the time line (not linear). On the intersections between the time and senses the supplementary addressing of a sense is shown.

One can see, how over time more and more senses are addressed. On the very right edge, after the bold vertical line a predication is given, how, according to the algorithm, the engineering system might evolve. On the top, pictures give an impression of the engineering system with the mentioned addressed sense.

For the elevator one can see how it started just with the kinesthetic sense (near field) – a button. Then light (visual) was added (far field). The sound was added (buzzer). The next step was to better coordinate the shape of the button (kinesthetic). Next the better coordination of the visual sense came up (video). The prediction are announcements or even that if the elevator is out of service or it is dangerous in case of fire, a bad smell (olfactory) might occur.

Figure 4 shows the same analysis for candles. Here again it started with one sense and others were added accordingly. Today candles address the visual, the olfactory, audio and kinesthetic part.

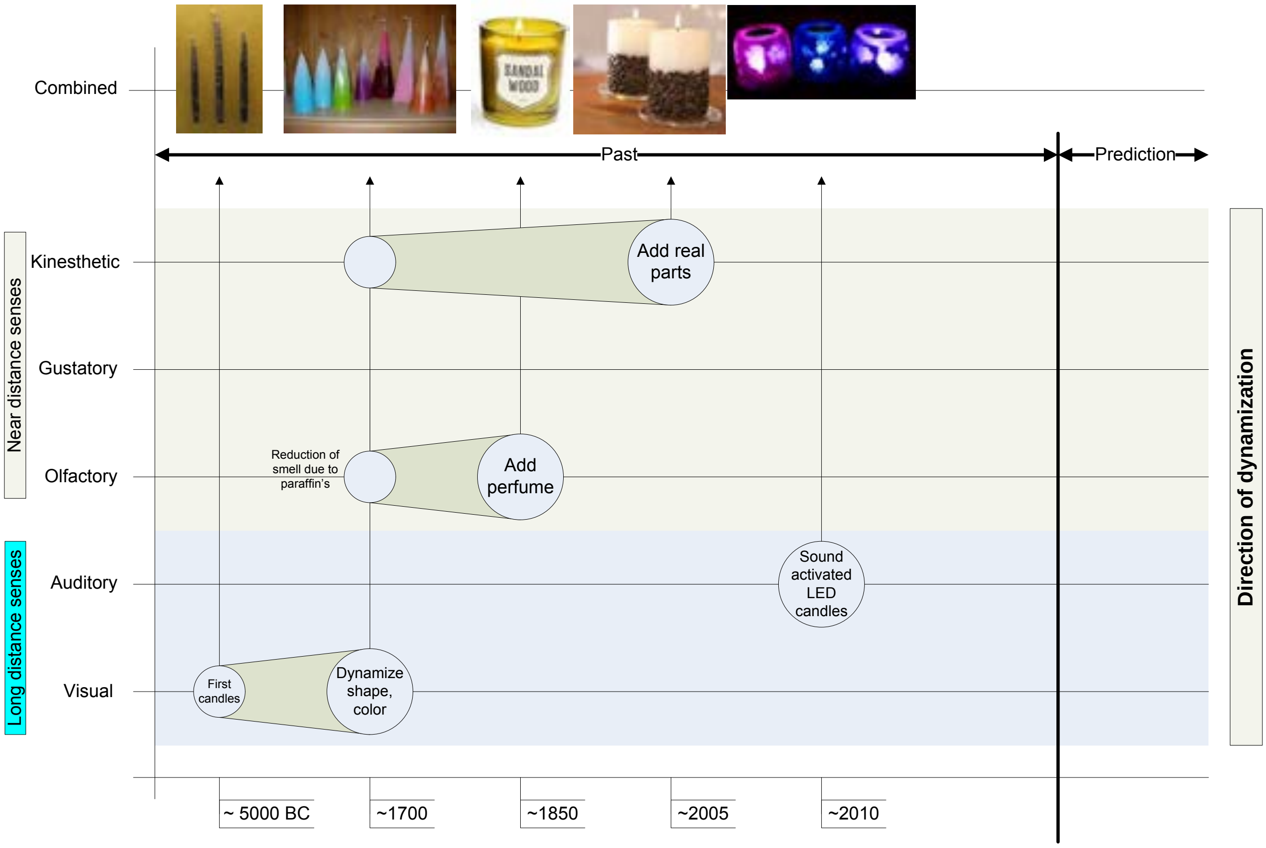

Fig. 4: Application of the algorithm to the engineering system “candle”

6. Implementation of the main provisions of research

As a result of the research two algorithms have been developed. The idea is to include the algorithms in the catalogue of trends under the main trend “Trend of Coordination”.

The suggested algorithm has been applied in several technical projects. This has shown that the algorithm is easily applicable and ideas for solutions are produced. The greater challenge is to find technology to realize the ideas. In the following described projects the algorithm has been applied and led to realization.

As kids have problems with standard MRs (Magnetic Resonance device, Fig. 5) in hospitals (loud, frightening, cold appearance) the machine could be turned into an adventure device with the odor of a jungle (visual, kinesthetic, olfactory).

Fig. 5: Engineering system MRI

With a soap manufacturing company, we developed the idea of integrating toys (kinesthetic) or sweets (tasting) into their soap (under development).

For the controls of a cable tie bonding machine we included vibration (kinesthetic) as a control signal for the strength of the tie procedure.

Lego is well known for their Product: one of the most structured toys and even industrial means that allows to build built any part with a basic set of highly shape coordinated bricks. Legos address the kinesthetic sense (feeling the bricks), the visual sense (colors) and partly the acoustic sense (there is a reproducible "click" sound when attaching the bricks to each other). With the slogan building anything Lego and Kellogg's offered a combination to address the taste sense as well (Fig. 6). The flacks are pressed into Lego brick forms with different taste. You can use them to build physical models and

you can eat them. As the bricks have with different colors as well different taste you can compose your taste as well.

Fig. 6: Lego Fun Snack

FIMO (trademark name of a product) is modeling clay that young kids use for playing but also tend to eat. It is not poisonous, but still parents do not like their kids eating that material. After using the algorithm, the idea was to add highly concentrated spice to FIMO. The kids played with the modeling clay as usual, but as soon as they took it into their mouth, they rejected FIMO due to the bad taste.

7. Conclusions

Technology trends have shown their applicability for a long time. As today products are more interacting with humans, an addition to the trend evolution of engineering systems has been presented. It is the increased addressing of the human senses. An algorithm for translating the trend into technology has been developed and the effectiveness has been demonstrated on different systems.

This paper is a brief summary of a more in-depth analysis of “Increased Addressing of Human Senses as a Trend”. The detailed study is available through the TMCC as it serves for a TRIZ L5 certification.

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INITIAL DISADVANTAGES IDENTIFICATION

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Abstract

Initial disadvantage is opposite of the project goal. However, in many cases, people may set the very obvious disadvantage as the initial disadvantage. But those obvious disadvantages are not the initial ones and therefore, the project goals are not correctly set and the project scope is very narrow. A new way of how to identify the initial disadvantages is proposed. By keep asking what the consequences it may causes, we can very easily determine which one is the most suitable initial disadvantage and then the project goal can be correctly determined.

Keywords: initial disadvantage, obvious disadvantage, project goal, cause effect chain analysis

1. What is initial disadvantage?

The initial disadvantage is the invert of the project goal. For example, if our goal is to reduce the cost, then our initial disadvantage is "the cost is too high." Disadvantages are the facts that prevent us achieving the goal. For example, the insufficient functions, excessive functions or harmful functions identified in function analysis are disadvantages. Cause Effect Chain analysis can find even more disadvantages. We may remove initial disadvantages by removing the disadvantages below the initial one to achieve the goal of the project.

2. The importance of determining the initial disadvantages

Cause Effect Chain Analysis is critical when solving practical problems. It can help to identify implicit disadvantages. Removing different key disadvantages can bring different opportunities to achieve the project goal. The more disadvantages we can find, the more opportunities we may have and the more chances we will achieve the goal of the project. A typical Cause Effect Chain Analysis is shown in Figure 1 (Ref: "TRIZ: The Golden Key to Open the Door of Innovation", Sun Yongwei & Sergei Ikovenko, Science Press, p57, 2015).

The disadvantage at the top is always set to be the initial disadvantage. And it is the starting point of Cause Effect Chain Analysis. It is like the target of the shooting game. Properly setting the right initial is critical when solving the practical problems.

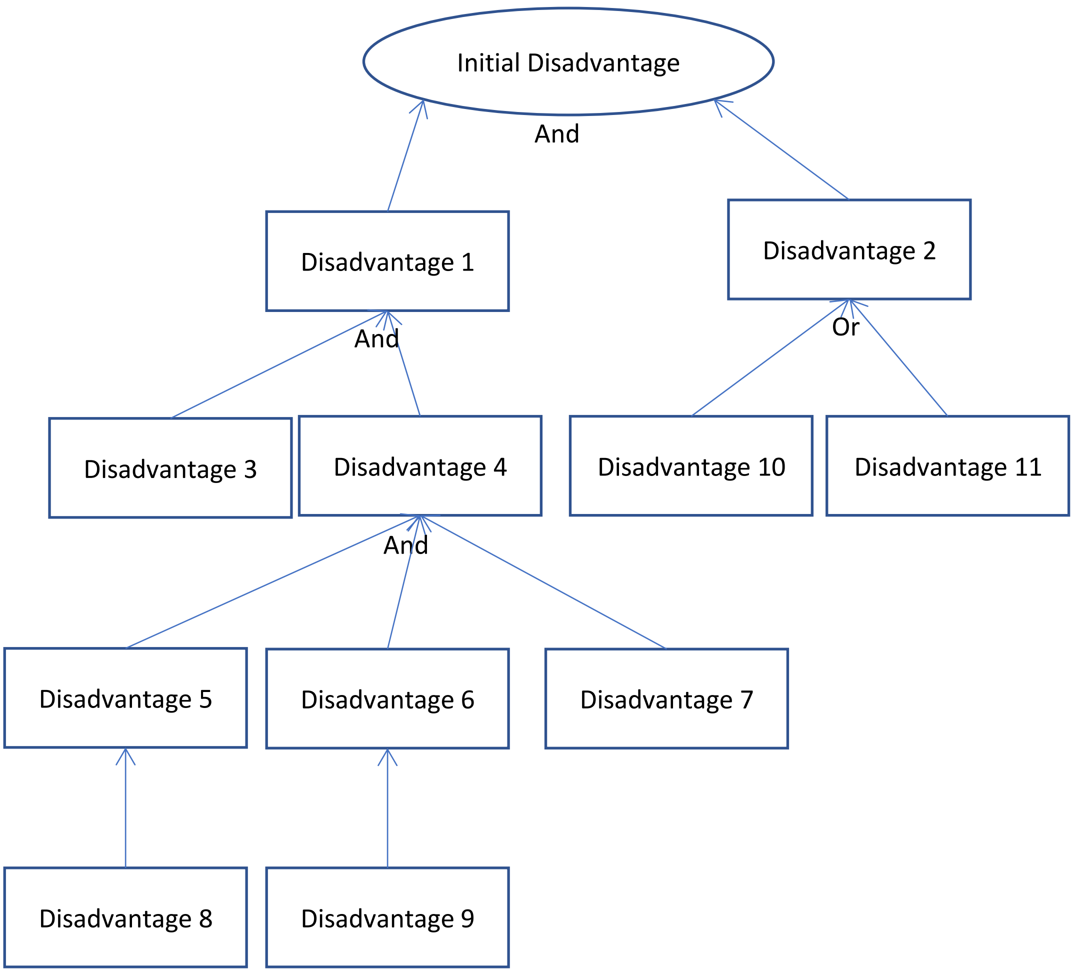

Fig. 1 Typical Cause Effect Chain

3. How to determine the initial disadvantages?

In many projects, it is not difficult to determine the initial disadvantages. We only need to invert the goal of the project, and then we set it the initial disadvantage. After that, we can apply routine Cause Effect Chain Analysis layer by layer to find the underlying disadvantages. Those disadvantages (chain) are linked with “And” or “Or” to form a complete chain. For example, if the goal of the project is to "reduce the cost", then “the cost is too high” can be treated as the initial disadvantage. If the goal of the project is to improve efficiency, then "efficiency is very low" can be used as the initial disadvantage.

But when we try to apply this approach to real problem solving, there may be challenges of identifying initial disadvantages. We found that different people may choose different initial problems. In many cases, the initial disadvantages are not that clear as we supposed, some may mistakenly set obvious disadvantage they meet at the beginning of the project as the initial disadvantage. In that case, our Cause Effect Chain Analysis will be led to a wrong direction, and therefore cannot find as many as possible underlying disadvantages, so that we will miss a lot of opportunities. For example, in Figure 1, if we take “Disadvantage 6” as the initial disadvantage, then what we can find out is “Disadvantage 9” only. We will lose the opportunity of identifying more disadvantages, such as “Disadvantage 3”, “Disadvantage 5”, “Disadvantage 7” ….

For example, there is a very famous case study in TRIZ community developed by GENTRIZ. In a paint process, the paint overflows because there is too much paint in the tank. (Ref: "TRIZ: The Golden Key to Open the Door of Innovation", Sun Yongwei & Sergei Ikovenko, Science Press, p57, 2015). The most suitable initial disadvantage may be “Paint overflows”. However, a lot of people may set “the paint sticks on the float” as the initial Disadvantage. That is because the adhesion between the float and the paint is very obvious and almost everyone can see it. If “the paint sticks on the float” is set as an initial disadvantage, the project scope will be much narrower than the one “Paint overflows”, and many disadvantages or opportunities may be lost. Another example is Triboelectrification problem, which is described in the same book ("TRIZ: the golden key to open the door to innovation", Sun Yongwei &Sergei Ikovenko, Science Press, p67, 2015).The initial disadvantage is “People feel pain (after he / she was hurt by static electricity when they contact the metal object in winter)”. However, most people may treat “Triboelectrification” as the initial disadvantage and therefore, much fewer disadvantages will be discovered and the project scope will be limited in a very small area. The number of potential solutions will also be limited because there are some other disadvantages in the project but we can’t be seen them.

How should identify the most reasonable initial disadvantages? We propose an iteration method to find the right initial disadvantages. In this approach, one of the obvious disadvantages is presumably set as the initial disadvantage. Normally it is not difficult to find one or two that kind of obvious disadvantages. We name this obvious disadvantage as Disadvantage N. After that, instead of finding the causes underlying the Disadvantage N, we will try to look up and find the consequences the Disadvantage N may cause. If we can find the consequence, then we can call it Disadvantage N-1. And then we will compare Disadvantage N and N-1 to see which one is more reasonable to be the initial disadvantage. If we think Disadvantage N is still more reasonable, we will stop the iteration and maintain our original decision. The Disadvantage N will be the most suitable initial disadvantage. On the contrary, if Disadvantage N-1 is better, we will take Disadvantage N-1 as the initial disadvantage and abandon Disadvantage N.

Following the same approach, we will continue to explore the consequences Disadvantage N-1 may cause. After repeating the same process, we will find the other ones, for example Disadvantage N-2, Disadvantage N-3, Disadvantage N-4… After the comparison, we will finally make the decision which one is the most suitable initial disadvantage.

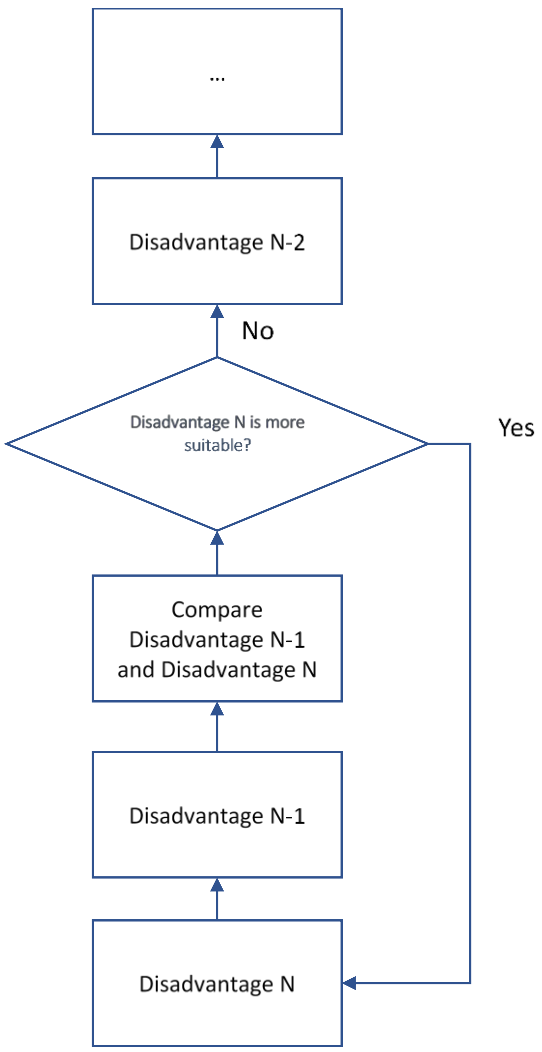

Fig. 2 Determination of Initial Disadvantages

If we take the "paint overflow" problem as the example, even though many people may set the "the paint sticks on the float" as the initial disadvantage because it is very obvious. We can follow the approach showed in Fig. 2 and determine the right initial disadvantage. What can "paint sticks to the float" cause? "The switch can't turn off the motor in time" may be the consequence. After the comparison, we may think "The switch can't turn off the motor in time" is better to be the initial disadvantage. And then we will continue to explore. More disadvantages such as "motor moves pump too much", "pump moves paint excessively", "paint overflows", "paint is wasted" and "cost increase due to the paint overflow" will also be identified. After the comparisons step by step, it is not difficult to decide that "paint overflows" should be the best initial disadvantage.

Another example is the "Triboelectrification" problem. It is very easy to find a very obvious disadvantage: Triboelectrification". And then we can follow the same approach and find out more disadvantages, such as "high voltage in the human body", "there is current between people and the metal object" and "people feel pain". After the comparison, we will determine "People feel pain (after he / she was hurt by static electricity)" to be the most suitable initial disadvantage.

After the initial disadvantages are identified, we can step by step build the cause effect chain based on routine Cause Effect Chain Analysis, and then we can continue to determine the key disadvantages to apply TRIZ tools to remove them.

It should be noted that the initial disadvantage hierarchy level should not too high and it should not be too low, either. If the selected initial disadvantages are too high, it will cause very serious deviation between the problems we are trying to solve and real project objectives. On the contrary, if the selected initial disadvantage is too low, the project scope will be very small, and we will lose a lot of opportunities which can help us to achieve the project goal. For example, in the example of "paint overflows", if we continue to use the iterative method, we will find more consequences, such as "paint is wasted too much". If we take "paint is wasted too much" as the initial disadvantage, we will deviate from the goal of the project (because the project is not intended to save paint). For example, in the Triboelectrification problem, if we continue to use the step-by-step iteration method, we will find other disadvantages, such as "the mood is not good". If we take this as the initial disadvantages, there will be big deviation from the goal of our project, because our project goal is not to please people).

4. Precautions for determining initial disadvantages

Application of the above iterative method can help us to effectively determine the initial disadvantages of the Cause Effect Chain, but still there are some items need to be paid attention to:

1. The determination of initial disadvantages and the Cause Effect Chain Analysis are team activities, not a job of a single person. The team members need to do intensive discussion and then make the final determination.

2. The initial disadvantage determined by iteration method above should get the agreement of all team members. It should be neither too high level, nor too low level.

3. Initial disadvantages identification and the Cause Effect Chain Analysis are not completely reversible. For example, we identified the disadvantages of N-1 as the initial disadvantages, but the disadvantages of N may not necessarily the immediate cause of the disadvantages of N-1. There may be some other disadvantages between Disadvantage N and Disadvantage N-1. We should follow rules and redo the Cause Effect Chain Analysis from the top to bottom.

5. Conclusion

This paper developed an iterative method which can help people to effectively determine the right initial disadvantages in the Cause Effect Chain Analysis, which is very critical for real problem solving.

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INTEGRAL S-CURVE ANALYSIS

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Abstract

The paper identifies drawbacks of the classical approach to S-curve analysis.

We propose to use practical value (V_p) as the integral parameter of the ordinate axis. The formula for this parameter is (Formula 1):

$$(1)\ V_p = \left(\prod_{j=1}^{n} s_j\right)^{1/n} = (s_1 s_2 \ldots s_n)^{1/n}$$

Where V_p – practical value;

Sj – customer's satisfaction with achieved value of each of the system's parameters P_j; n – number of the parameters.

The factors in this equation, which represent the degree of customer satisfaction with the achieved value of each parameter, can be calculated as follows (Formula 2):

$$S = \left(\frac{\uparrow P - \uparrow P_{\min}}{\uparrow P_{\max} - \uparrow P_{\min}}\right)^{\frac{KL}{1-L}} \tag{2}$$

Where S – user satisfaction with achieved parameter value P;

K – weight coefficient, $0 \le K \le 1$

L – market saturation coefficient, $0 \le L \le 1$

If measurement units are such that improving the system involves decreasing parameter value (e.g. electric car's energy expenditure measured in kw/h per 100 km driven), the formula changes only slightly (Formula 3):

$$S = \left(\frac{\downarrow P_{\min}(\downarrow P_{\max} - \downarrow P)}{\downarrow P(\downarrow P_{\max} - \downarrow P_{\min})}\right)^{\frac{KL}{1-L}} \tag{3}$$

P_{min}, P_{max} are minimum necessary and maximum allowable values of the parameter (i.e. the improvement limit is P_{min} and not P_{max}).

The proposed approach:

- makes possible localization the entire system one stage of the S-curve, which fully legitimizes the use of a set of indicators and standard recommendations pertaining to each stage

- allows developing at quantitative level recommendations on the prompt withdrawal of the system to the market and on the return of the system from the third stage to the second one
- makes it possible to predict the moment of the transition of the ES to the third stage
- reveals the fundamental mathematical causes of the slowdown in development at the first and third stages and the rapid development at the second stage

Key words: S-curve, parameter, integral.

1. Introduction

Initial situation

S-curve analysis has a long history. It was developed by Genrikh Altshuller [1, 2, 3] for the forecasting of engineering systems development. At the same time, he developed the first methods of positioning an engineering system on the stages of an S-curve by the number and level of patents, system effectiveness, and profitability. This approach assumed that the entire engineering system is on one stage: otherwise, all these indicators make no sense. In addition, the main parameters were indicated on the ordinate axis in plural, or not indicated at all.

Later, a different approach was suggested [4]: to build a separate S-curve for each parameter. This may be feasible, but leads to a situation where the system is at different stages in different parameters.

For example, a car may be in the third stage in the “speed” parameter, in the second stage of the “safety” parameter (the opportunities for improvement are far from exhausted), but only in the first stage in parameter of "autonomy of control” (Figure 2).

Figure 2. MPVs of a car

At the same time, the engineering system must still be placed at one stage as a whole, otherwise all indicators and typical recommendations are inapplicable.

In [5] it was proposed to make “ideality” the ordinate axis. This approach solves the problem, but encounters the inefficiency of existing methods to calculate ideality.

In [6], these shortcomings have been analyzed in detail. Among them, the unaccounted influence of market saturation, ignoring the essentially nonlinear relationship between the actual value of the parameter and the consumer's response to it, etc.

However, an important problem remains - predicting when the system will approach the third stage. Simple extrapolation is unsuitable because the improvement of a parameter depends on several unpredictable factors, such the appearance of new materials and technologies, making it difficult to create informed forecasts.

There is one more question, rather academic but interesting. Why does the S-curve exactly have this form? What inhibits the development of systems in the first and third stages? It is believed that at the first stage, developers have insufficient resources, and on the third stage, the resources of the system itself are practically exhausted. However, what this specifically means is still not very clear.

Disadvantages of the existing approach. Goal of the development

Therefore, existing approaches to S-curve construction are either impractical or inaccurate, lacking utilization of advanced sets of S-curve stage indicators and their typical recommendations. In addition, the existing approaches are not suitable for quantifying the time required to reach the third stage. Finally, they do not give a complete answer to the question of the causes of the steady manifestation of S-curves in the development of various engineering systems.

Therefore, the goal of this paper is to eliminate these shortcomings (impracticality and inaccuracy), as well as to identify the "natural" unavoidable causes of slow development of an ES at the first and third stages.

2. Hypothesis

In [6], an equation was proposed for calculating the ideality of a system (more accurately, its practical value). The equation would connect the actual values of the main parameters of the system with the intervals of their evaluation, the relative importance, and degree of saturation of the market (Formula 1):

$$V_p = \left(\prod_{i=1}^{n} S_i\right)^{1/n} = (S_1 S_2 \ldots S_n)^{1/n} \qquad (1)$$

Where Vp – practical value;

Si - user satisfaction with the value of parameter Pi;
n – number of parameters.

The factors in this equation, which represent the degree of customer satisfaction with the achieved value of each parameter, can be calculated as follows (Formula 2):

$$S = \left(\frac{\uparrow P - \uparrow P_{\min}}{\uparrow P_{\max} - \uparrow P_{\min}}\right)^{\frac{KL}{1-L}} \qquad (2)$$

Where S – user satisfaction with achieved parameter value P;

K – weight coefficient, $0 \le K \le 1$

L – market saturation coefficient, $0 \le L \le 1$

If measurement units are such that improving the system involves decreasing parameter value (e.g. electric car's energy expenditure measured in kw/h per 100 km driven), the formula changes only slightly (Formula 3):

$$S = \left(\frac{\downarrow P_{\min}(\downarrow P_{\max} - \downarrow P)}{\downarrow P(\downarrow P_{\max} - \downarrow P_{\min})} \right)^{\frac{KL}{1-L}} \quad (3)$$

Pmin, Pmax are minimum necessary and maximum allowable values of the parameter (i.e. the improvement limit is Pmin and not Pmax).

With the ability to practically reduce any number of the main parameters of a system to one integral criterion, one can construct its development curve (Figure 2):

$$V_p = (\prod_{i=1}^{n} S_i)^{1/n} = \sqrt[n]{S_1 S_2 \ldots S_n}$$

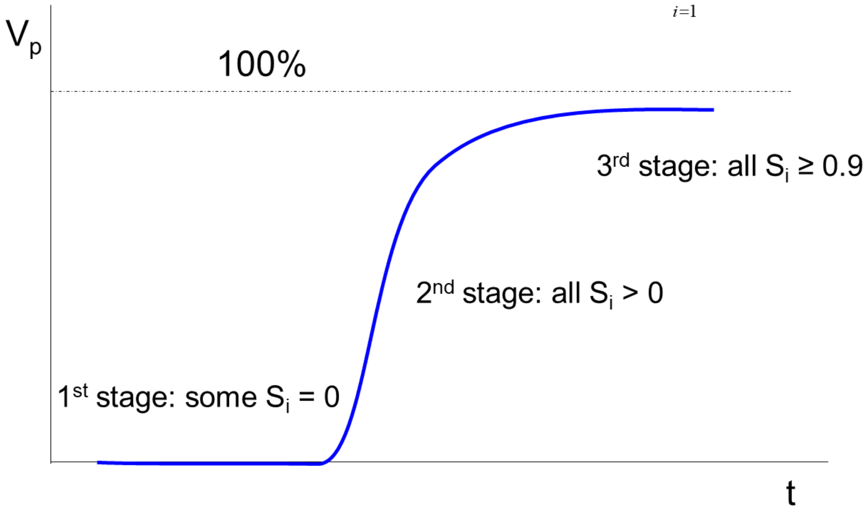

Figure 3. Integral S-curve

The formula (1) uniquely determines the S-shaped curve form. Indeed, since the practical value (Vp) is the root of a product, the equality of at least one factor to zero automatically turns it to zero. The first stage of the curve lies on the abscissa. In practice, it means that the system will not enter the market until at least one of its main parameters (affecting, by definition, the purchase decision) is outside the valuation interval. For example, an aircraft will not be bought if, say, its altitude ceiling is below treetop height and the carrying capacity is less than the pilot's weight. Yes, people may still build planes, test them, and demonstrate at exhibitions, but they will not be practical or commercially successful.

Another example is the jet pack. It is an interesting invention and may have many applications, but the fuel capacity of current models provide only about one minute of flight – a drawback that completely cuts its way to the market. The Olympic torch with its help can be ignited, but the enthusiasm of consumers - alas! (Figure 3):

Figure 4. Jetpack

From this formula, the mathematical justification of the well-known [6] recommendation follows: at the first stage, only the defects that directly impede entry into the market should be identified and eliminated. Formula (1) points to them directly in quantitative form.

The second stage also finds its explanation in a natural way. When all factors overcome the zero mark, the increase in each of them immediately affects the results and the curve rushes up.

And, finally, the third stage - when all the factors have reached the values of 0.85 - 0.9, their further increase has almost no mathematical effect on the overall result, hence the slow development. In addition, further improvement is very difficult to achieve when everything is already polished and optimized.

Formula (1) suggests a way of further improvement for such systems - the addition of new main parameters. Although this reduces Vp, returning the system to the second stage, the decrease paradoxically does not affect competitiveness. Moreover, competitiveness only grows, because this parameter is zero in competing systems, which provides a temporary monopoly on the market. If, for example, someone makes a car capable of flying over traffic jams (albeit slowly, awkwardly and with large fuel consumption), he will immediately get a decisive advantage: buy this car or stand in traffic! (Figure 4):

Figure 5. "Jumping car"

However, the fourth stage disappears with this approach. Indeed, practical value and ideality does not decrease under normal conditions (excluding all sorts of cataclysms such as the fall of the Roman Empire, after which the recipe for cement were forgotten in Europe for centuries). In reality, the phenomenon of the decline in main indicators is observable! The point is that at the fourth stage, the system goes to another market niche with other properties (relative importance of parameters, valuation intervals, etc.), and thus it is necessary to build a separate S-curve for it.

This approach allows us to predict, with a certain degree of accuracy, the moment the ES transitions to the third stage - simply by extrapolating the second stage to the intersection with the integral development limit, which is always equal to 1 or 100%. In this case, a significant number of individual parameters levels the fact that the rate of their change is difficult to predict - individual jumps and delays somewhat compensate each other.

Conclusions

Thus, a new method for constructing S-curves is proposed, based on the use of a single integral parameter - the practical value (Vp). This solution has several advantages:

The proposed integral parameter Vp can be calculated quantitatively based on somewhat accessible data. In extreme cases, some of them can be determined by the method of expert evaluation or even ignored - the accuracy will decrease, but the formula will remain applicable.

Vp is dimensionless, expressible in fractions or percentages. This makes it possible to plot curves on a single graph relating to different systems.

It makes it possible to localize the entire system on the S-curve, legitimizing the use of a set of indicators and standard recommendations pertaining to each stage.

It allows the development of quantitative recommendations for the prompt withdrawal of the system to the market and on the return of the system from the third stage to the second one

It makes it possible to predict, with some confidence, the moment of the transition of the ES to the third stage

It reveals the fundamental mathematical causes of the slowdown in development at the first and third stages and the rapid development at the second stage

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IS TRIZ EASY, OR NOT?

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Abstract

Nobel Prize winner Daniel Kahneman in his book "Thinking, Fast and Slow" [1] explains two modes of how our brains think.

Those findings are profound for learning, promoting and using TRIZ. Based on Kahneman's work, this paper answers such questions as:

Why is it that, as Valeri Souchkov says „TRIZ is easy to explain, but much harder to apply"? [2]

Should TRIZ be promoted as being easy? What are side effects of selling TRIZ as an easy remedy for every business? Are there any better ways to offer TRIZ? What about culture - should we change anything in presenting the image of TRIZ?

This article is written from the perspective of a training company "selling" TRIZ to business decision makers, to share experience and opinions and to start a discussion. The focus is put on the question: how decision makers perceive TRIZ to decide to invest in it or not?

Keywords: TRIZ application, Kahneman, perceiving TRIZ by business.

1. Kahneman's findings for TRIZ

Daniel Kahneman is a psychologist who received a Nobel Prize in the field of economy in 2002 for his research explaining how people make decisions. In his book "Thinking, Fast and Slow" [1] Kahneman explains two modes of how our brains think.

Kahneman's **slow thinking** is process of diligent, conscious thinking, as it is with a driver who drives a car for a very first time. The driver is intensively thinking about mirrors, transmission, acceleration pedal, clutch, brakes, steering wheel, speedometer and other indicators plus all the objects in the proximity of the car. After some practice the same driver is not thinking so intensively. All those processes are done by more automatic, **fast thinking** mode. So the driver's brain is capable to cope with a conversation during driving because these processes are done in the autonomous mode. Conversing is very difficult during the first drive because the brain of the driver is overloaded with processing all the needed information using the slow thinking mode. The fast mode uses less neurobiological resources, so this may explain why we are cognitive misers by nature, saving on conscious, intensive thinking whenever we can.

If humans intuitively prefer to think less, than TRIZ is difficult when put into practice, because **well established habits are difficult to change**.

Kahneman's team found that our brains put all routine tasks into subconscious (fast) processes when we master them. So we tend to take shortcuts when thinking: this explains the psychological inertia known in TRIZ. Psychological inertia starts when we mismatch thinking mode with problem calibre, so we try to solve a difficult problem with these fast thinking mode. Fast thinking is quick, but so inaccurate that we lose sight of many possible solutions and often get into dead end prototyping the first weak idea which comes to mind and experiencing failure, thus wasting a lot of precious time. The time we paradoxically wanted to save. But turning to slow mode of thinking is not intuitive. It is where TRIZ comes to help. TRIZ changes our thinking to slow mode needed for solving difficult problems.

This observation helps to understand why TRIZ is not so easy to apply. It is reasonably easy to explain [7], but its application by organizations sometimes gets into a quagmire. There is too little data at hand of how often TRIZ implementation is not a success, but the gut feeling is – quite a lot because of present relative low popularity of TRIZ as presented in [8] - but it should be noted that this presentation raised much discussion and many disagree with the findings. TRIZ is not intuitive. It takes too long time to convert thinking with TRIZ to fast mode, and before it happens, fast mode is unable to cope with difficult problems.

Example: if you change from classical Project Management (waterfall cascade) into Agile – it is change of culture and habits, you need a special coach (called Scrum Master in Agile Scrum) to ensure that people are not coming back to old routines [3]. The hypothesis of the author is that to achieve successful TRIZ application, big effort is needed to ensure that new habits are well established.

In the Era of USSR's TRIZ, it was found by practice, that 3 months of intense training is the minimum to change habits to make a TRIZ practitioner. This length might be an indicator why TRIZ is far more difficult to apply than many other tools, for example, Lean. Strong habits rooted by traditional education are very difficult to change.

We humans are cognitive misers [1]. Without long training, as Kahneman shows, we tend to automatically switch the mode our brain works to the ineffective fast mode. So building on this article I propose a change for the trend of „Reduction of human involvement" (Fig.1). I propose to divide every stage involving human to two stages. First, it should be the "slow thinking" mode, and then the saving brain energy "fast thinking" mode (Fig.2).

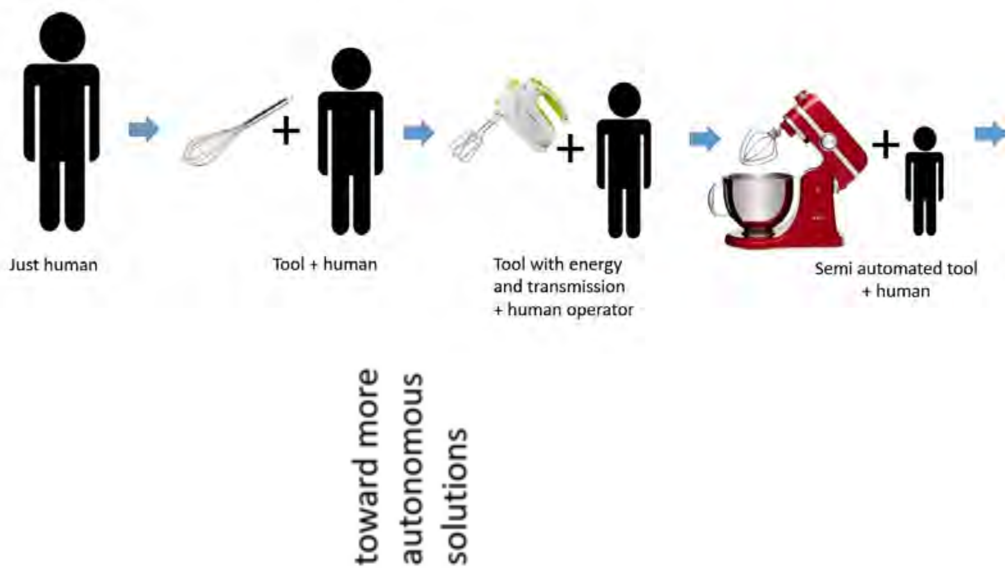

Fig1. Trend of human involvement reduction [by the author]

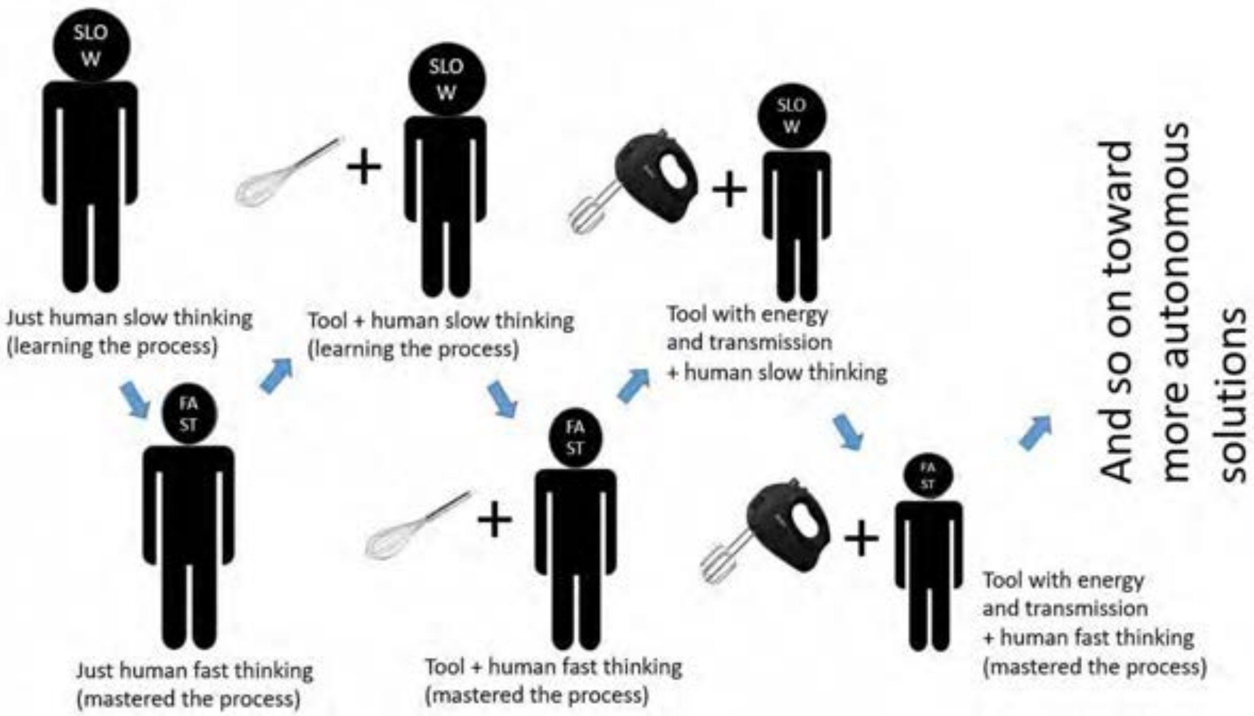

Fig. 2 The same Trend of human involvement reduction including the switch of mode from "slow" to "fast" thinking mode according to Kahneman [proposal by the author].

2. Applying TRIZ – what is the weakest link?

After many years of offering Project Management and a few years of offering TRIZ training and consulting, the author has come to the conclusion that TRIZ is a very good solution for some of the clients but not for all. It depends mainly not only on needs but also on the maturity level of the client.

The factor for making decision to apply TRIZ or not should be the main restricting parameter (weakest link) in the client's organisation. Is the client halted with well-defined problems, which he cannot solve, or something else? Some clients do not have an innovation-friendly culture, some need to reorganize their processes. In the author's opinion TRIZ has more chances for successful implementation if the client is well organized and has established frameworks, such as Lean or Six Sigma, to benefit most from TRIZ.

The assumption is - it is not beneficial to go with TRIZ for clients who are in chaos and need order. Similar to Maslovs's pyramid of human needs, TRIZ for organizations seems to be somewhere at the top of the pyramid whereas order and good atmosphere are more basic and thus reside at a lower level.

Some clients even don't know what problems they have, their actions are very chaotic. Proposing them regular, systematic, rich implementation of TRIZ is like teaching them to run before they know how to walk. TRIZ addresses a narrow part of the organisation processes. If problem-solving is the weakest link, than TRIZ should bring highest return on investment.

There exist genuine tools for organisation change for acomplishing higher innovation culture level. After getting there, the organization shall prize TRIZ for its value. The only way to make TRIZ beneficial before the company is well organized might be temporary "rent a TRIZ-gunfighter" for quickly shooting down a painful problem.

There are also different levels of scale – individuals may resist TRIZ, as well as whole organizations. A nice trick to try TRIZ with large organizations is to start with pilot projects on a team scale. This way, TRIZ can be tested for results with low risk, when a temporary project is run to validate the use of TRIZ within the specific conditions of the organization. So using another level of scale can change entry of TRIZ.

Lilly Haines-Gadd, manging director of Oxford Creativity, with long experience of implementing TRIZ to organisations, notes how the appetite for TRIZ changes according to maturity of organisations: *"Startups don't often adopt TRIZ because they are trying to work out how to do things – they are innovating in their field of work, and are not usually interested in innovating their way of working. They also don't need new concepts – they are usually trying to put them into practice. They then go through a period of growth – all things that require innovative thinking, but they are so focused on how to make things work they usually are not interested in TRIZ.*

Organisations once they have grown then try to gain efficiencies – using things like Lean and Six Sigma. Again, TRIZ could help in this.

Once organisations have become lean and efficient they have usually lost all the "waste" processes, time, and maybe people which might have created innovation. This is the point at which many companies realize they need TRIZ – because they have lost either the ordinary practice of innovation or have focused so much on employing people who are good at maintaining the status quo, rather than coming up with disruptive new ideas" [4].

The author was unable to find in scientific literature the perspective of how business decision makers perceive TRIZ. Living in the business world for decades, the author is sure, that any new thing like TRIZ (as for many TRIZ is still a novelty) is perceived as a black box with a strange name. Typical business leaders are not interested in the mechanism inside if the black box does not produce benefits: it should give high return with low risk to be welcomed. Many clients are interested only with the monetized outcome, they are not much interested with the processes inside the box. It seems there are only few who loved the inside beauty of TRIZ tools, others are confused with kaleidoscope of new names of tools being offered to them.

Specially Six Sigma sells itself to business leaders by promising cost savings, and has worked out how to measure the impact of its tools. This makes it easy to say “yes” for business leaders. TRIZ does not cover the whole innovation process (Fig 3), for example it does not provide tools for prototyping and testing ideas. In comparison to Six Sigma it is more difficult to measure impact of TRIZ and thus selling it to business.

In the opinion of the author, TRIZ is not a panacea for every business sickness. It should be aplied with care. It is well known that are situations where involving TRIZ didn’t pay back. Some positive examples (like Samsung) are overused. Not every company is at the place, where Samsung was around the turning of the XXI century. TRIZ is certainly great to help with generating solutions but lacks strong ‘back end’ of the process (as explained by Toru Nakagawa promoting six-box scheme Fig. 3, although ‘front end’ with newest TRIZ tools is no longer weak this days).

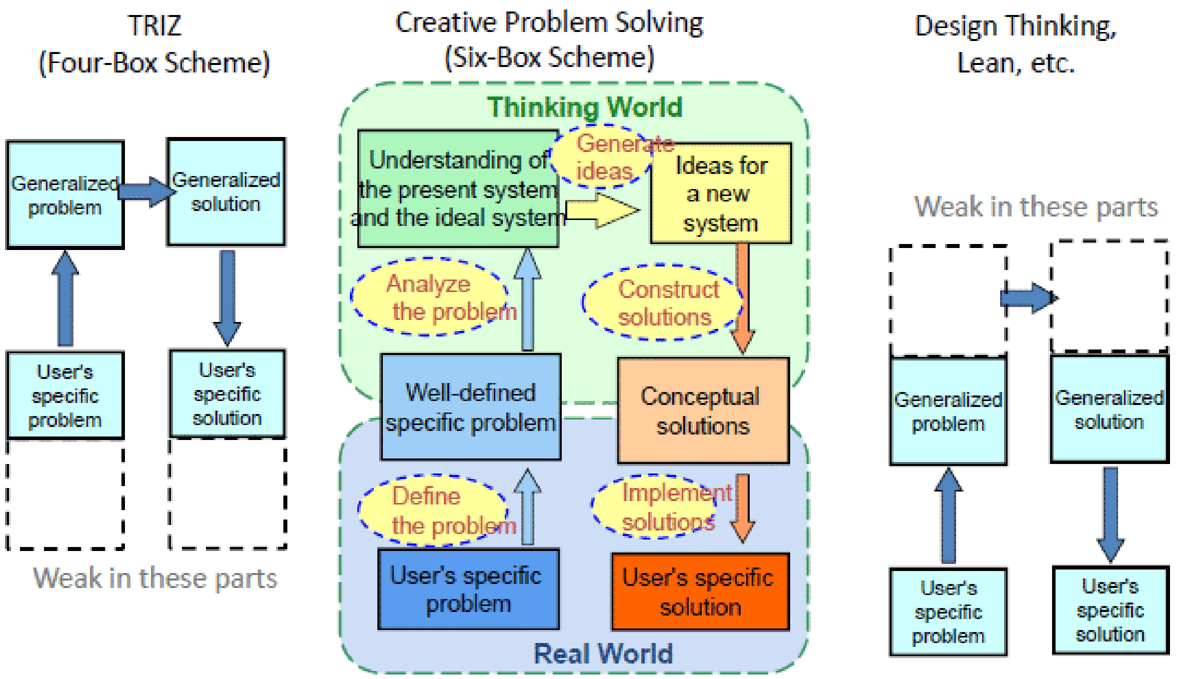

Fig 3 Comparison of TRIZ, USIT and frameworks like Design Thinking and Lean by Toru Nakagawa [5].

So the TRIZ advocates should not propose TRIZ as a magical panacea for every business. It implementation should be considered with caution. If not, the “TRIZ does not work” statement will gain popularity. The author observed this when the Agile Project Management tools were entering Poland at the first phase. (2001-2007).

TRIZ is usually not the lowest hanging fruit for a business decision maker. Often it is enough to change culture or the way a company is organized to get faster benefits. TRIZ, apart from rare cases, provides return in longer time (in the sense of systematic change resulting in a stream of ongoing innovations).

3. Conclusions

The main difficulty is in going against natural habits. TRIZ is easy to explain, but application is difficult because it requires the users to change their mode of thinking. As explained earlier, humans are inclined to do things with less thinking (fast mode). TRIZ requires to go against this trend, back to the diligent, slow thinking mode. This is the hard part when applying TRIZ, because it requires changing strong habits [6].

TRIZ shall not be proposed as panacea, because it is a great medicine only for a specific part of a business - generating solutions. So when we offer TRIZ to decision makers, after getting to know the situation of the client, sometimes we shall postpone proposing TRIZ. Specifically, when problem solving is not the restricting parameter for this organisation in this time.

Proposing TRIZ as easy panacea for all sicknesses may raise false expectations at the client side and in effect put a bad name to TRIZ itself.

In this paper, the author shared his ideas from his own observations and perspective, lacking support of data many times. However he strongly believes this issue should be a matter of discussion within the TRIZ community.

Acknowledgements

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MAPPING TRIZ PRINCIPLES TO ELECTROMECHANICAL CONVERSION APPLICATIONS

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Abstract

TRIZ core theory and continuing ongoing research present multiple works showing specialized examples of Inventive Principles for the most diverse fields, both technical and non-technical, including for instance microelectronics, informatics, chemical engineering, business and quality management, marketing, and even human factors and ergonomics. Such examples are of great help for teachers and practitioners, offering a chance of immediate understanding by analogy and inspiration for metaphorical thinking during the creative application phase, when the translation from the chosen Inventive Principles to real world solution is the most challenging part for the inventor. On the other hand, TRIZ offers many tools adopted for knowledge systematization. On the side of power engineering and electric machine world the classical approach is the distinction between static machines, rotating synchronous, rotating asynchronous, DC machines and variations thereof, but the topology spectrum, the rated power and application ranges are so wide, that it results at times very difficult to capture. In this paper, a classification of electric machines according to TRIZ Inventive Principles applied stepwise to the simplest electromagnetic coupled device will be shown, accounting for both the technological development and the state of the art. Such a classification can serve as enabler for future deeper analysis procedures for technology landscaping; starting from a simplified generalized function model, examples for Principle application will be given showing different developments of the baseline according to an evolutionary approach, offering also a new viewpoint in a discipline where TRIZ full potential has still to bloom.

Keywords: TRIZ, Electric Machines, Forecasting, Function Model, Evolutionary Approach

1. Inventive Principle Example Collections

TRIZ application often relies on collections of examples of Inventive Principles' application to facilitate the creative process by analogy. Many tools that implement the Altshuller's Matrix, while prompting the suggested Inventive Principles, offer lists of problem solutions as examples of application of the specific Principle. This practice represents a powerful help to think metaphorically, especially for beginners and during innovation workshops where the audience has little or no TRIZ literacy and the facilitator is asked to lead the team and introduce the method at the same time. In literature, various example lists classified by discipline have been reported; the list by E. Domb [1] is often referenced. In addition to that, many other application fields have been documented [2], such as Architecture, Business, Chemistry, Customer Satisfaction, Education, Food Technology, Marketing, Sales, Advertising, Quality Management, Service Operation Management, Social. D. Mann [3] focused on Inventive Principles for Business, comparing by statistical analysis the frequency occurrence of the Principles in the original Altshuller's Matrix, for his updated version dating to 2010 and for Business applications. He states that example lists add value to the users who lack the time required to develop an entire TRIZ process. Users can still profit from the method thanks to a ranked list of Inventive Principles, even if the full power of TRIZ is in this way somehow lost. His study shows that the frequency of occurrence of Inventive Principles for the Altshuller's matrix and the specific business domain of application could be different; this suggests that it could also occur for other fields. This also seems confirmed looking at the several collections of example for different applications listed in [2], for which it has been calculated how many examples have been recorded for each Inventive Principle; Figure 1 shows the results for six selected application fields, even if this kind of evaluation lacks the statistical rigor that underlies the Altshuller's Matrix.

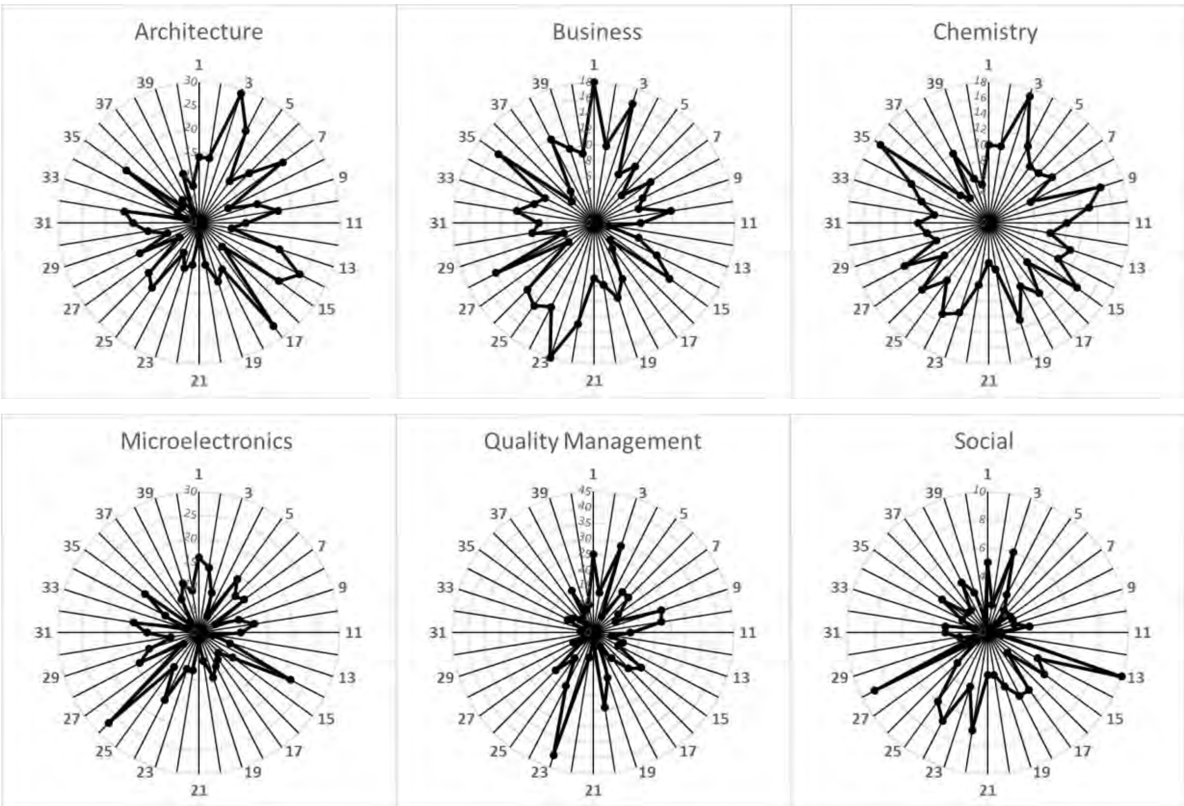

Fig. 1. Inventive Principle Occurrence for six application fields

Nevertheless, those collections of examples facilitate TRIZ teaching, learning and application, and their relevance is even more important and popular for non-technical areas, for which a patent database is not available [4]; a frequency based ranking could offer one more tool to the TRIZ user. In Paragraph 2 the value of an organized collection of Inventive Principles for Electric Machines is discussed.

2. Relevance of Inventive Principles Examples for Electric Machines

A list of examples of Inventive Principles for the electric machine space can answer the difficulties to bridge TRIZ theory and regular adoption; in this field, especially among beginners, often difficulties arise during TRIZ application; different reasons have been collected as feedback among workshop participants and listed below:

1. TRIZ is often perceived as more effective for mechanical applications,
2. Many Inventive Principle examples are non-electric-machine related,
3. TRIZ is sometimes perceived as far-fetched with respect to complex system problems,
4. For electric circuit applications graph-like solutions would be preferable.

TRIZ generality and abstractness, which constitute its power, present the drawback of being felt sometimes fuzzy to more than one engineer, especially the ones who show the strongest psychological inertia, to the detriment of methodology acceptance. Examples can be powerful door openers and indeed smoothen the learning process: their absence for a specific domain sometimes impair immediate application. A collection of dedicated examples can be greatly beneficial among electric machine specialists. Compiling a meaningful list is not straightforward: in fact, observing the electric machine traditional list, it can be noticed that for most of the machines that could serve as immediate examples the simultaneous application of more Principles applies. Moreover, being the technology in the mature stage, many variants of the same baseline devices can be found and it is extremely difficult to build a comprehensive picture of all the existing devices, usually ordered by incremental variations of topology, constructive considerations, drive, application and power range. This is reflected also in the education system, where the traditional introductory courses offer an overview of the main four kinds, ordered as transformers, synchronous, asynchronous and DC machines, mirroring the historical theory development, which starts from the discovery of the rotating magnetic field principle for electromechanical conversion; subsequent specialization courses present a limited selection of all possible variations, taught following a topological classification; the different machines are presented as derived as step-wise specializations of the four primitives; this results in a monumental body of knowledge, difficult to organize and learn. One solution could be given by the Trees of Technology Evolution as presented by Shpakovsky [5]: trees are graphs that capture all possible versions of a technology product in an organized classification structure, allowing to present a huge amount of information to audiences like customers and students. Evolution Trees are built following TRIZ criteria, so that the evolution of a product following the trend can be shown; niches of still unrealized versions can be identified with a detailed description. From an evolution tree the steps at which innovations were introduced can be visualized, identifying empirically the most useful Inventive Principles, listed and organized in a structure. The added value of an evolutionary tree resides also in its huge potential in education field, where the focus on creativity teaching and learning is steadily increasing [6]. The effectiveness of this approach has been researched by V. Berdonosov [7-9]; it has also been proven whilst training students for creative imagination and knowledge systematization at the same time, based on prior TRIZ training. Evolution trees have also been applied to object-oriented programming; in addition, a general TRIZ-based scheme to design education pathways has been proposed. Effective creativity teaching has also been addressed by Cascini et al. [10], using an indirect learning-TRIZ-by-doing approach through games (TETRIS project), while in [11] Oget describes a TRIZ- based pedagogy for teaching English in Latvia, for which no prior TRIZ knowledge is requested to learner. In this paper a first attempt to combine the two points of view, namely the collections of examples for application by analogy and evolution trees, is illustrated, together with a reverse- mixed approach. The starting point of this work is a traditional list of electric machines, for which the recognizable Inventive Principles and applied Trends have been recorded. A tree of dependencies has also been built, as more deeply explained in Paragraph 3.

3. Building an empirical database

3.1. Selected machines

A preliminary set of twenty-five most common machines [12] has been considered as initial sample for this investigation. The sample size, however small with respect to the entire spectrum of electric machine variants, is evaluated according to Formula 1:

$$X = \overline{X} \pm \frac{t \cdot s}{\sqrt{n}} \ . \ (1)$$

where the terms represent:

$\overline{X}$: estimation of the population mean

s: estimation of population standard deviation σ

n: sample size

t: factor dependent from the sample size,

taking a 95% confidence interval a sample size of 20 means t-factor ~ 2.2, instead of best case 1.96 as show in Table 1; the sample size has been thus considered acceptable for this pilot study.

Table 1

t-factor as a function of sample size

n (sample size)	t-factor (95% of confidence interval)
2	12.71
3	4.30
6	2.57
10	2.26
50	2.00
∞	1.96

The first categorization of the listed machines distinguishes between stationary devices, like inductors and transformers, and rotary machines. In [13] the function model for a generalized machine has been built, starting from the proposition that all rotary machines are a specialization of the generalized abstract electromagnetic joint [14] [15]; this allowed to derive the most typical Inventive Principles addressing common problems for all the devices, grouped by topology, materials, controls, and other aspects of power engineering. For this work the same generalization has been followed, and two primitives for all electromagnetic devices have been considered, respectively the generalized electromagnet (consisting of a ferromagnetic core and a winding) for the stationary machines and the aforementioned electromagnetic joint (where the rotating magnetic field is generated) for the rotary ones. Borrowing the object-oriented programming jargon, where generalized objects are distinguished as classes and subclasses according to a class inheritance tree, such two primitives can be seen as the parent classes of the two preliminary trees. All other electric machines have been considered as derived from those two. At each derivation step, the recognizable and most relevant Inventive Principles have been listed. Table 2 shows the complete list of the considered devices on the first column; mutual dependencies have been also recorded and later captured in the graphs; in other words, it has been established from which device the selected machine can be considered a subclass by application of a set of Inventive Principles reported in the second column. The third column captures the Trends of technical System Evolution that can be recognized at each evolution step, numbered consistently with the Table 3 reported in Paragraph 3.2.

For example, the Permanent Magnet Transverse Flux Motor (PMTFM) is a class derived from the Permanent Magnet Synchronous Motor (PMSM) applying the Inventive Principle 17- Use Another Dimension, that captures the introduction of the transverse flux; the PMSM in turn is a subclass of the Synchronous Motor, to which the Inventive Principles 25- Self-Service and 28-Mechanic Substitution have been applied; in fact the excitation winding has been replaced by permanent magnets, which provide the magnetic flux by their intrinsic material properties; The Synchronous Motor is a subclass of the generalized electromagnetic joint, to which the Inventive Principle 13-The Other Way Round and 20-Dynamization have been recognized. As a default, for synchronous machines the operation as a generator has been chosen: the general synchronous motor is thus considered as derived from the synchronous generator applying the Inventive Principle 13-The Other Way Round. For asynchronous machines the operation as motor has been considered as default: asynchronous generators are as well considered as derived by motors applying the Inventive Principle 13-The Other Way Round. The traditional electric machine classification has been developed primarily for internal rotor rotating machines; it follows as main criterion the operating principle (i.e. attraction of opposite poles, minimization of reluctance paths and so on). The proposed classification starts also with the operating principle as the only attribute of the parent class electromagnetic joint; whilst building the evolutionary trees, other important attributes are added to the children classes, such as magnetic circuit layout (or topology), reciprocal position of active parts, recognized Inventive Principles and Trends. The described PMTFM is so defined by the attributes Synchronous Motor (Type), Surface Mounted (topology), Permanent Magnet (active excitation), Transverse Flux (topology), Inventive Principles 17 and Trends 7 and 9; Inventive Principle and Trends describe the evolutionary step with respect to the parent class Permanent Magnet Synchronous Motor Surface Mounted, being the different flux arrangement the application of the aforementioned Inventive Principle and Trends.

Table 2

Electric Machine List, Inventive Principles and Trends

Description	Inventive Principles	Trends
Electromagnet	19	1
Inductor Monophase	19,20,35	3
Inductor Multiphase	26,35	3
Monophase Transformer	19,35	3,6
MultiPhase Transformer	26,35	3,6
Monophase Transformer - more secondaries	26	3,6
Multiphase Transformer - more secondaries	26	3,6
Tokamak	2,15,17,35,36	8,11
Stellarator	5,28,35	7,9
Electro Magnetic Joint	5,15,19,20, 24,26,28	2,3,8,11
Synchronous Generator smooth rotor	20	8
Synchronous Generator salient pole	4,14,35	6,9
Synchronous Motor	13,20	8
Superconducting generator	20,36	2,5,9,11
PM magnet synchronous motors, surface mounted	25,28	2,5
PM magnet synchronous motors, buried	7,25,28	7,9
Brushless motors	2,25	6,10
Permanent Magnet Transverse Flux Motors	17	7,9
Permanent Magnet Disk Type Motors	17	7,9
Linear Electric generators	4,17	7,9
Inside Out Synchronous Generator	13	7
Asynchronous motor wound rotor	4,15,16,22	5,6,9
Asynchronous motor squirrel cage	5	5,7
Asynchronous monophase motor	2,22	3,6
Asynchronous generator	13	6
DC Generator (Dynamo)	20,33	5,6,9
DC Motor	13	5,6,9

3.2. Trends as Criteria

Trends of Technical System Evolution are the basis of the theory of Evolution Trees by Shpakovsky [5], where classical TRIZ Trends have been reorganized as a list of nine evolution patterns, along which the evolution of devices can be followed. For the present analysis the classical list of Trends according to G. Altshuller [16] and reviewed by GEN3Partners has been considered, reported in Table 3. For each machine considered in Table 2, the applicable trends have been later added as a feature, as explained in Paragraph 4.

Table 3

Trends of Engineering System Evolution used as Classification Criteria

1	Trend of S Curve Evolution
2	Trend of Increasing System Ideality
3	Trend of Transition to the Super-system
4	Trend of Increasing Completeness of System Components
5	Trend of Decreased Human Interaction
6	Trend of Increasing Coordination
7	Trend of Increasing Controllability
8	Trend of Increasing Dynamism
9	Trend of Un-even Development of System Components
10	Trend of Increasing Degree of Trimming
11	Trend of Flow Enhancement

This allows to build a tree showing the step-wise evolution of electric machines based on topological variations.

4. Preliminary Evolution Trees for Electric Machines

A first simplified Evolution Tree for Electric Machines Primitives is shown in Figure 2: the relevant evolution patterns characterizing the branches (or evolution steps) have been identified. It must be noticed that at topological level, all moving devices deriving from the electromagnetic joint present three potential reciprocal positions between magnetic flux layout and direction of motion, covering all possibilities in 3D suggested by the Inventive Principle 17-Use Another Dimension: radial, linear (including tubular) and spheroidal. The three layouts are applied to all possible categories of known devices; in fact, traditional rotating machines are represented by the In-Plane option in a cylindrical coordinate system, while linear and planar machines are better described within a Cartesian-plane representation. Toroidal and Spherical devices are also captured if the correct reference frame and flux layout are considered. In this way for each device subclass three possible branches of the evolution tree can be derived. The preliminary developed Tree has been split into two sub-trees for readability; they are depicted separately in Figure 3 and 4 respectively; all potential topological layouts have been not explicitly drawn and only the existing variations captured; all the mentioned options should be anyway kept into consideration for innovation sessions and strategic studies, since each reference frame variation offers a possible new device class introduction. Information about the most relevant Trends and Inventive Principles along the Tree branches have been added; further considerations about Inventive Principles will be discussed in Paragraph 5.

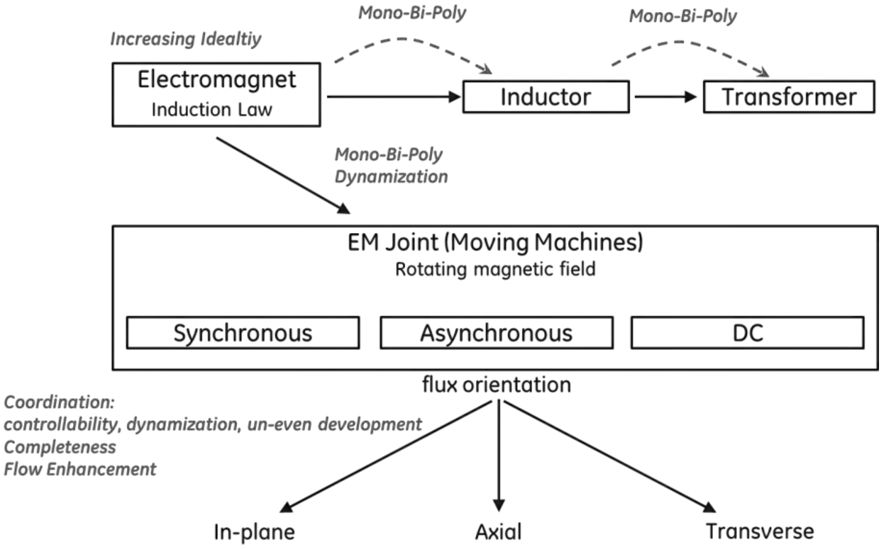

Fig. 2. Preliminary Evolution Tree for Electric Machines; in *italic* Trends of Engineering System Evolution

This is intended to serve as a template for future tree development; some observations can already be inferred: for static machines the most relevant trend is Mono-Bi-Poly, the main evolution feature being the number of windings as a characteristic of inductors and transformers. For rotating machines, the importance of Mono-Bi-Poly still holds, applied not only to the number windings but also to other parameters, such as number of poles; other Trends acquire a foremost relevance, such as the Trends of Increasing Coordination, with all different aspects captured by its sub-trends. For most of the topological variations the Trends of Increased controllability and Un-Even Development can be identified, since each variation addresses the need for increased performance for a specific application. The Trend of Flow Enhancement is also instrumental since it describes all the optimization effort aimed to increase efficiency, that is, optimize energy flow by minimizing losses.

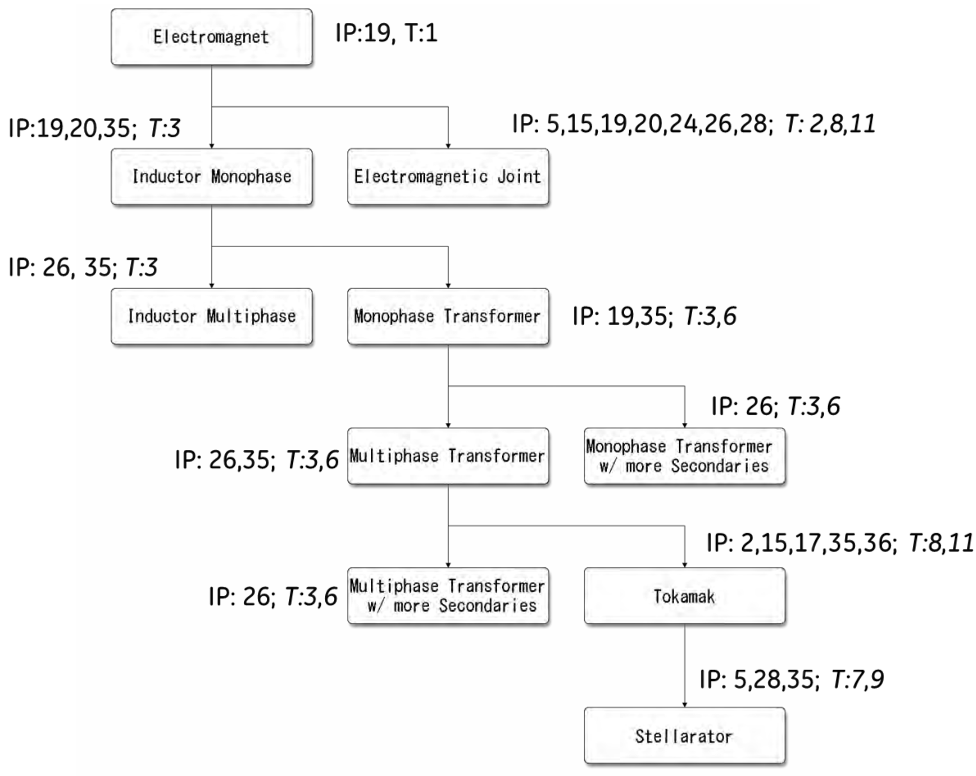

Fig. 3. Evolution Tree for Electric Machines, focus on Stationary Devices. Trends in *italic*

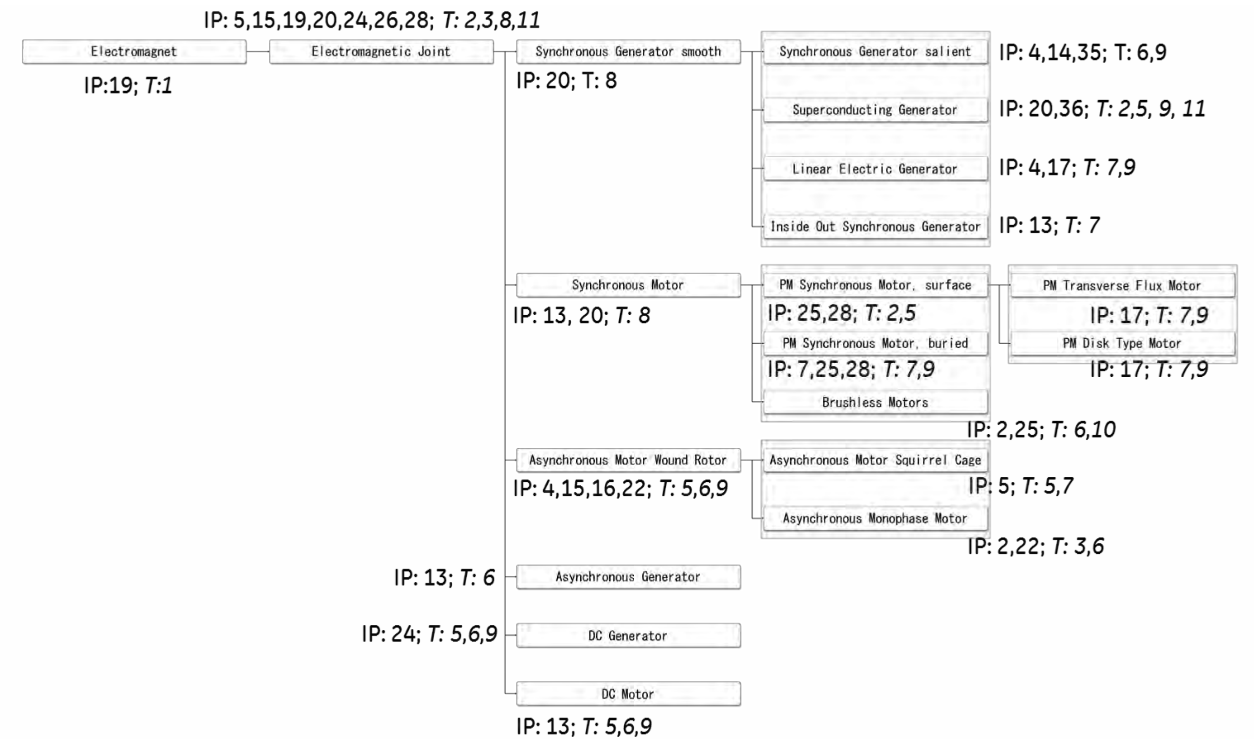

Fig. 4. Evolution Tree for Electric Machines, Moving Devices. Trends in *italic*

5. Inventive Principle Examples for Electric Machines

5.1. Inventive Principles adding material and topology considerations

A separate list of Inventive Principles has been identified while considering the adoption of typical active materials and constructive arrangements for machine excitation, as shown in Table 4; the elements of the first column capture the typical solutions adopted in recommended design practice [17]: for instance, in the case of electric conductors, the use of separate strands or Litz wires abides to Inventive Principle 1- Segmentation.

Table 4

Inventive Principles for Electric Machines – Active Materials

Active Material	Applied Inventive Principle
Electric Conductors	1,3,12
High temperature Conductors	10,28
Superconductors	35,36
Permanent Magnets: ferrites	3,28,35
Permanent Magnets: rare-earth based	3,28,35
Permanent Magnets: skewed	3,17,35
Permanent magnets: Hallbach arrangements	3,17,35
Magnetic Shape Memory Alloys	18, 25,28,35

5.2. Inventive Principles Examples from the Tree Structure

Table 5 reports the collection of examples of application of Inventive Principles derived from the observation of the Evolution Trees built for the electric machines listed in Table 2.

Table 5

Inventive Principles for Electric Machines – Example List

IP	Evolution Tree Machines	Materials	Other
IP1-Segmentation	-	Electric condutors (Litz)	Switches in cascade
			Multi-tap windings in transformers
	-	Segmented PMs	Maglev with segmented fed stator
IP2-Taking Out	Tokamak		
	Brushless motors		
	Asynchronous monophase motor		

	Inside Out Synchronous Generator		
IP3- Local quality	Synchronous Motor	El. conductors orientation wrt flux	
		Hallbach PM	
		Skewed PM	
IP4-Asymmetry	Synchronous Generator salient pole		Split pole to start small motors
	Linear Electric Generators		
	Asynchrounous motor wound rotor		
IP5-Merging	Electro Magnetic Joint		
	PM magnet synchronous motors, surface mounted		
	PM magnet synchronous motors, buried		
	Asynchrounous motor squirrel cage		
	Stellarator		
IP6-Universality	-	-	Universal Motor
IP7-Nested Doll	Tokamak		
	PM magnet synchronous motors, buried		
IP10-Preliminary Action	-	High Temperature Conductors	Split pole to start small motors
IP11-In Advance Cushioning	-		Shield insertion to avoid losses
IP12-Equipotentiality	-	Electric conductors	
IP13-The Other Way Round	Synchronous Motor		
	Inside Out Synchronous Generator		
	Asynchrounous generator		
IP14-Spheroidality – Curvature	Synchronous Generator salient pole	Skewed PM	
IP15-Dynamics	Tokamak		
	Electro Magnetic Joint		
	Asynchrounous motor wound rotor		
IP16-Partial or Exces-sive Action	Asynchrounous motor wound rotor		deflux in PM machines
IP17-Another Dimension	Permanent Magnet Transverse Flux Motors	Hallbach PM	
	Permanent Magnet Disk Type Mo-tors	Skewed PM	
	Linear Electric generators		
IP18-Mechanical Vibration		Magnetic Shape Memory Alloys	
IP19-Periodic Action	Electromagnet		Multiharmonic
	Inductor Monophase		

	Monophase Transformer		
	Electro Magnetic Joint		
IP20-Continuity of Useful Action	Inductor Monophase		
	Electro Magnetic Joint		
	Synchronous Generator smooth rotor		
	Synchronous Motor		
	Superconducting generator		
	DC Generator (Dynamo)		
IP21-Skipping	-		
IP22-Blessing in Disguise	Asynchrounous motor wound rotor		Eddy current brake, eddy current passive shielding
	Asynchronous monophase motor		
IP23- Feedback	-		Self-regulated current transfomer
			Electrodynamically suspended MAGLEV
IP25- Self-Service	PM magnet synchronous motors, surface mounted	Magnetic Shape Memory Alloys	
	PM magnet synchronous motors, buried		
	Brushless motors		
IP26- Copying	Inductor Multiphase		
	MultiPhase Transformer		
	Monophase Transformer w more secondaries		
	ThreePhase Transformer w more secondaries		
	Electro Magnetic Joint		
IP27- Cheap Short-Living Objects	-		Fuses, sacrifical electrodes
IP28- Mechanic Substitution	Stellarator	High Temperature Conductors	Linear machines vs. Mechanical Gears
	Electro Magnetic Joint	Magnetic Shape Memory Alloys	
	PM magnet synchronous motors, surface mounted		
	PM magnet synchronous motors, buried		
IP31- Porous Materials	-		Flux bridges in PM machines, in situ magnetizaation
IP32- Colour Change	-		Optical position encoders
IP33-Homogeneity	DC Generator (Dynamo)		Homopolar machines
IP34-Discarding and Recovering	-		In situ magnetization

IP35-Parameter Change	Inductor Monophase	Hallbach PM	
	Inductor Multiphase	Magnetic Shape Memory Alloys	
	MultiPhase Transformer	Skewed PM	
	Tokamak		
	Stellarator		
	Synchronous Generator salient pole		
IP36-Phase Transition	Tokamak		
	Superconducting generator		
IP40-Composite Materials	-		Dual-phase material

5.3. Comparison with conclusions from Generalized Function Model

In [13] the generalized function model of the electric machine and the subsequent contradiction resolution suggested a set of Inventive Principles considered valid for all classes of derived machines, arranged in four groups: Addressing Machine Topology, Addressing Materials, Addressing Control and Others. The scope of the present work covers mostly the two areas Machine Topology and Materials. Comparing the Principles emerging from [13] with the highest occurrences in Table 5, it can be seen how both approaches (generalized model and the Evolution Tree Analysis) consistently identify the most relevant common sub-sets of Inventive Principles: 4- Asymmetry, 13- The Other Way Round, 14- Curvature, 17- Another Dimension, 19- Merging, 28- Mechanic Substitution, 35- Parameter Changes for the category Addressing Machine Topology. The category Materials in both cases shared the Inventive Principles: 31. Porous Materials, 36- Phase Transitions. The similar outcome resulting from the present analysis and the one described in [13] gives the authors a stronger confidence in the validity of the approach.

6. Conclusions and Further Developments

The presented analysis allowed deriving a first list of examples of Inventive Principle applications in the electric machine domain, for a preliminary sub-set of devices. The study analyzed the step-wise development of electric machines, captured in an Evolution Tree. The most common Inventive Principles have also been identified; they have been compared with the outcomes of the analysis of a generalized function model by the same authors and the two approaches showed similar results. The derived Evolution Tree and the collection of examples can be fruitfully applied both during TRIZ teaching sessions, innovation workshops and regular practice. This study represents a preliminary analysis, by no means exhaustive, to be refined towards a more complete model; the necessary next steps have been identified and listed below:

- Database enlargement to all the relevant existing electric machines, with also special machines based on other physical effects, e. g. piezoelectric devices

- Extension to new material developments that could represent potential game-changers for this technology, e. g. nanomaterials, composite and the new additive manufacturing solutions, intentionally not considered for the scope of this work

- A more robust statistical analysis, ideally patent-based, aimed to identify the most common Principles for this domain

- Identification of the most relevant Trends in electric machine development with the same procedure used for the Inventive Principles

- Further development of the evolutionary approach, so that also the strategic value is retained

- Identification of the new development branches of the Evolution Tree that could represent promising novel solutions

Moreover, the evolutionary approach can be very useful at corporate level in order to create a living database as a basis to formulate innovation strategies and trade-off studies during the everyday design activity; it can be organized and completed adding constructive details such as number of poles, phases, power range for all the considered devices and thus serve as a reference. This will be the long-term goal for the development of this work.

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MODERN TRIZ AND THE CONCEPT OF ANTIFRAGILITY. FRIENDS, ENEMIES OR FRENEMIES?

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Abstract

In this paper we discuss the relevance of the concept of Antifragility, introduced by Nassim Taleb, to the Theory of Inventive Problem Solving (TRIZ).

As defined, "Antifragility is a property of systems that increase in capability, resilience, or robustness as a result of stressors, shocks, volatility, noise, mistakes, faults, attacks, or failures." The concept has already been applied in many fields including risk analysis, computer science, engineering (individual examples/cases of the simplest engineering systems are available), transportation planning, etc.

The concept of Antifragility appears to be novel and elegant; however, it is based only on some empirical findings, and there are few practical recommendations on how to achieve Antifragility.

Modern TRIZ is known as a systematic approach to solving complex technical problems and improving/creating engineering systems. TRIZ has its own toolset which includes formalized analytical and problem solving tools.

This paper is an attempt to illustrate how TRIZ tools can be adapted so that the Antifragility property can be introduced into existing systems or into systems we are creating. The proposed approach can be used not only for enhancing the Antifragility of engineering systems, but also for social, managerial, economic, and other systems.

The authors' suppositions are supported with a number of illustrative case studies.

Keywords: antifragility, modern TRIZ, combining theories.

1. Introduction

By definition, antifragility is a property of systems that increase in capability, resilience, or robustness as a result of stressors, shocks, volatility, noise, mistakes, faults, attacks, or failures. It is a concept developed by Professor Nassim Nicholas Taleb in his book "Antifragile: Things That Gain from Disorder" [1]

As Taleb explains in his book, papers and public speeches, antifragility is opposite to fragility, but it is fundamentally different from the concepts of resiliency (i.e. the ability to recover from failure) and robustness (that is, the ability to resist failure).

The concept of fragile, robust and antifragile is represented in Fig. 1.

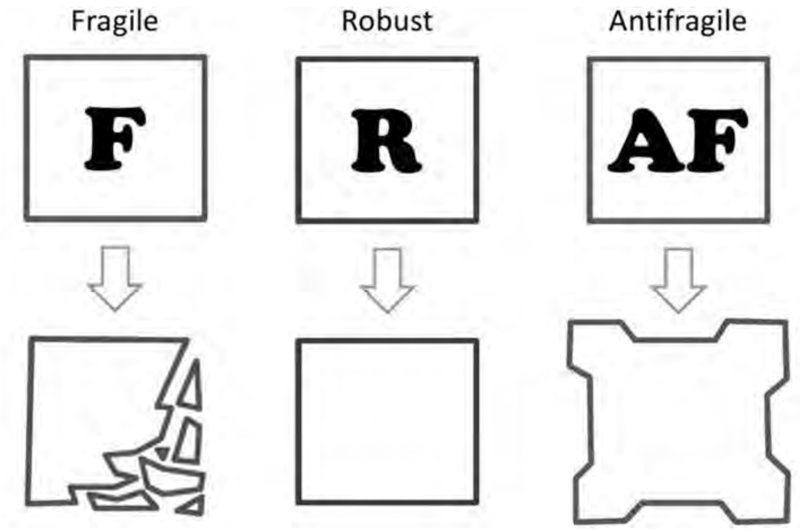

Fig. 1. Depiction of Fragility Spectrum [2]

Antifragile systems, according to Taleb, can be social systems, evolution, culture, political systems, the process of creating technological innovation, corporate survival, legal systems, the human body and psychology, mythological heroes, etc. As is typical when a new term/definition is introduced, it became clear that antifragility, as a property, had already appeared and been identified in different systems around us. This property has not been described systematically, however, and requires further study and practical recommendations to make it more useful.

Taleb states, "By grasping the mechanisms of antifragility we can build a systematic and broad guide to nonpredictive decision making under uncertainty in business, politics, medicine, and life in general—anywhere the unknown preponderates, any situation in which there is randomness, unpredictability, opacity, or incomplete understanding of things.

"It is far easier to figure out if something is fragile than to predict the occurrence of an event that may harm it. Fragility can be measured; risk is not measurable…" [1]

The concept of antifragility is supported with a set of simple recommendations. The main goal of these recommendations is to lead the development of our complex artificial systems in the most simple and natural way. To this end, Taleb uses the notion of heuristics [1]: "Heuristics are simplified rules of thumb that make things simple and easy to implement. But their main advantage is that the user knows that they are not perfect, just expedient, and is therefore less fooled by their powers. They become dangerous when we forget that."

In the authors' opinion, making systems antifragile is one of the most important directions for creating, improving and exploiting modern complex systems under uncertain conditions. Therefore, the goal of this article is to investigate how the concept of antifragility can be complimented and enhanced with TRIZ.

Initial research on the compatibility of antifragility and TRIZ is published in [3]

2. Clarification of Research Objectives

"I hear and I forget. I see and I remember. I do and I understand"
Confucius

This well-known quotation illustrates different levels of understanding and knowledge. Taleb's findings can be characterized as "I see and I remember." In this paper, the authors suggest making the next step in developing the concept of antifragility: "I do and I understand."

So, the beginning of this research focuses on Engineering Systems that can be described well in TRIZ terms.

Also, the authors study the antifragility of Engineering Systems and discuss the connection between antifragility and the philosophy and toolset of TRIZ. The following results are revealed and described in this paper:

- Broader interpretation of antifragility as a possible behaviour in developing/changeable systems, as well as limitations to applying the term antifragility;

- Ways of creating, formulating and renewing heuristics based on TRIZ logic and tools –methodological recommendations on how to create heuristics for achieving antifragility.

At the moment, there are not many publications available on the topic of creating antifragile engineering systems. See, for example, [3,5,6]

3. Concept of Antifragility

3.1. Dynamics of Antifragility in the Life Cycle. Examples

The different ways of system development is depicted in Fig. 2.

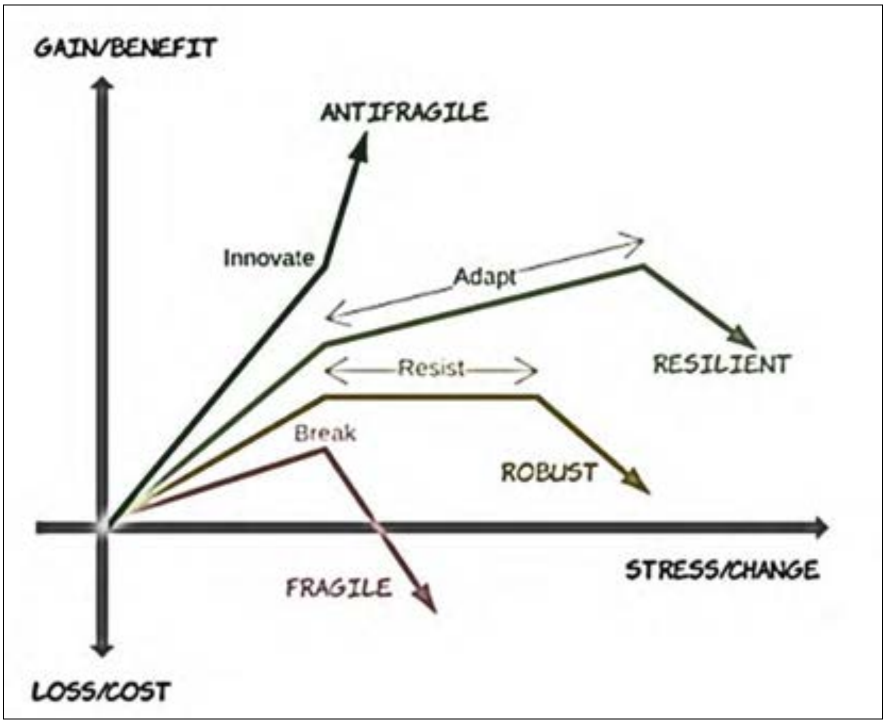

Fig. 2. How systems respond to stress/change [4]

Such visualization allows us to identify several essential details of antifragile behaviour.

In this paper the dynamics of antifragility development are discussed. In addition, by studying systems' life cycles, specific mechanisms of antifragility were identified.

Example #1. Coordination in time and antifragility.

Overcompensation is one of the important means of antifragility. Taleb [1] emphasizes the importance of overcompensation again and again. His notion can be significantly enhanced if we apply the TRIZ Trend of Increasing Coordination (sub-trend – coordination of rhythms or coordination in time).

In sport medicine, overcompensation is well-known and has been thoroughly researched. If we refer to the available data, however, it is not easy to see the connection between antifragility and overcompensation (see Fig. 3)

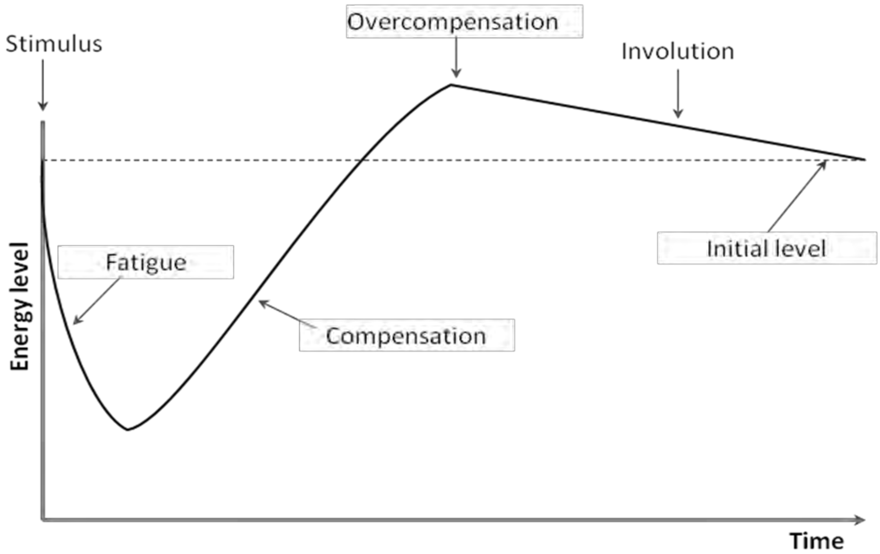

Fig. 3. Typical dynamics of overcompensation

When repeating such cycles in a sequence, as shown in Fig.4, the conditions and results of antifragility become clear. It is important to note that if the sequence is changed, the results will be totally different. There may be no improvement, or even deterioration (for example, as in the effect of overtraining).

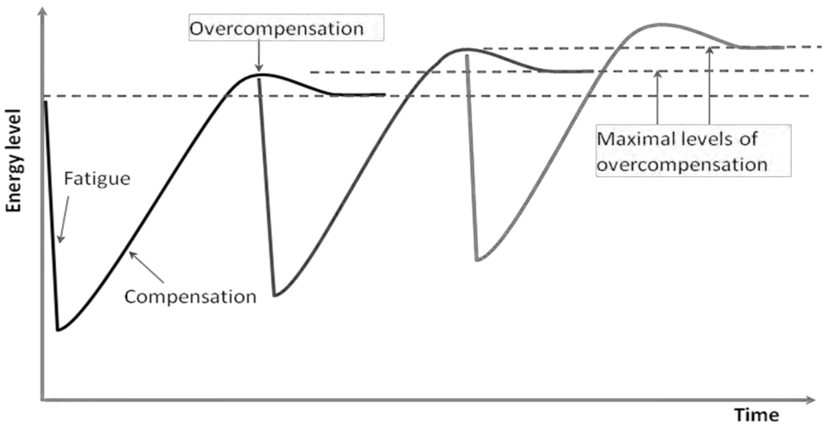

Fig. 4. Coordination in time of fatigue and compensation

Example #2. Adaptive Inactivity as a mechanism of antifragility

At present, the function of sleep (an essential function of all living beings) has not yet been clearly defined, and there are continuous scientific debates on this topic. One hypothesis proposed by Jerome M. Siegel [7] is that sleep is an Adaptive Inactivity. Since this adaptation is needed for future non-defined stresses/impacts, the authors believe that Adaptive Inactivity can be considered as one of the mechanisms of antifragility. In fact, during sleep certain processes take place that prepare the animal for some unforeseen future event.

Another simple example is the aging of unfinished products between technological operations, without applying any external actions: time is all that sets the internal aging processes in motion. This technological step is widely applied in different fields, e.g., aging is used to relax residual stresses in moulded metal products, to homogenize ceramic mixtures and dough, etc.

In the examples above, coordination in time is very important for developing antifragility.

3.2. How antifragile systems work. Examples analyzed

Let us now consider a few examples of simple engineering systems to illustrate how the mechanisms of antifragility develop and work.

Example #3. Hadfield steel

Hadfield steel (also called manganese steel or Mangalloy) is a steel alloy containing an average of around 13% manganese. Hadfield steel is known for its high impact strength and resistance to abrasion once in its work-hardened state.

Mangalloy is made by alloying steel, containing 0.8 to 1.25% carbon, with 11 to 15% manganese. Mangalloy is a unique non-magnetic steel with extreme anti-wear properties. The material is very resistant to abrasion and will achieve up to three times its surface hardness during conditions of impact, without any increase in brittleness which is usually associated with hardness. This allows mangalloy to retain its toughness [8].

In 1816, a German researcher Carl J. B. Karsten noted that adding fairly large amounts of manganese to iron would increase its hardness without affecting its malleability and toughness, but the mix was not homogeneous and the results of the experiment were not considered to be reliable [8].

According to [9], "...the large nonuniformity of hardness distribution in the deformed Hadfield steel is not caused mainly by the austenite grain boundary and grain orientation of the indentation plane, but by the underlying non-homogeneous substructures, with higher hardness in multiple-twin regions and lower hardness in dislocation-prevailing regions."

In this case, antifragility is achieved because alloying steel with manganese leads to the formation of twins when plastically deformed. (Crystal twinning occurs when two separate crystals share some of the same crystal lattice points in a symmetrical manner.) These twins prevent micro cracks and enhance the wear resistance of Hadfield steel.

Under stress/load this process develops even more if the structure has been pre-developed. This is a good illustration of how antifragility works.

Example #4. Self-locking knots

Self-locking knots are well known and they have been used for a long time in different areas: mountaineering, fishing, marine activity, surgery, macramé, etc. The main idea of a self-locking device is that it automatically fixes itself in place. With a self-locking knot, the more force we apply when pulling a rope, the tighter the knot we have. This is due to the special position of the rope, which, when a pulling force is applied, leads to increased contact area and a tightening force (see Fig.5).

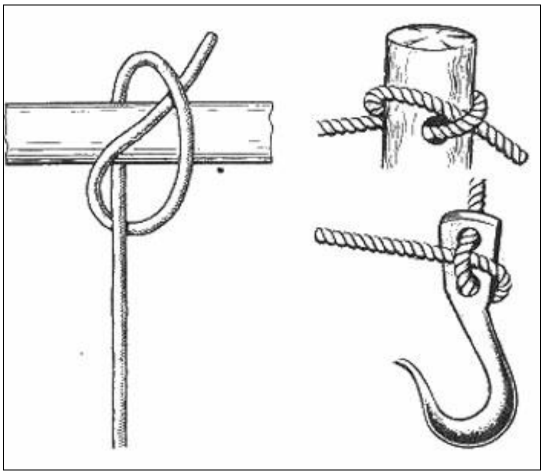

Fig 5. A few examples of simple self-locking knots [10]

Even from a quick analysis of the examples above, it becomes clear that the definition of antifragility requires further clarification:

- Parameters. When developing antifragility, it should be clear which specific parameter(s) are needed to achieve antifragility. For example, to increase the wear-resistance of steel even more, alternative ways of alloying should be considered.

- Working window: range of stress actions in which antifragility should appear. For example, specific properties of materials are usually identified in a certain range of parameters; the strength of human muscles and bones can be increased if antifragile training is applied in the defined range of stresses.

- Time interval in which antifragility is expected. In other words, we need to identify time intervals for processes that lead to developing or losing antifragility. For example, Hadfield steel can increase and retain its strength during a limited interval of time.

4. TRIZ tools for developing antifragility

Let us start with the classical tool – Inventive Principles. These principles can be used for developing heuristics.

In this paper, the authors do not include case studies detailing how the Inventive Principles were applied. Their applicability is clear from the mechanism of antifragility described in this paper.

Fig.6 depicts possible Inventive Principles that can be used for developing antifragility. The principles in Fig. 6 are collocated in a special order which allows us to see their applicability BEFORE, DURING and AFTER external stress/impact.

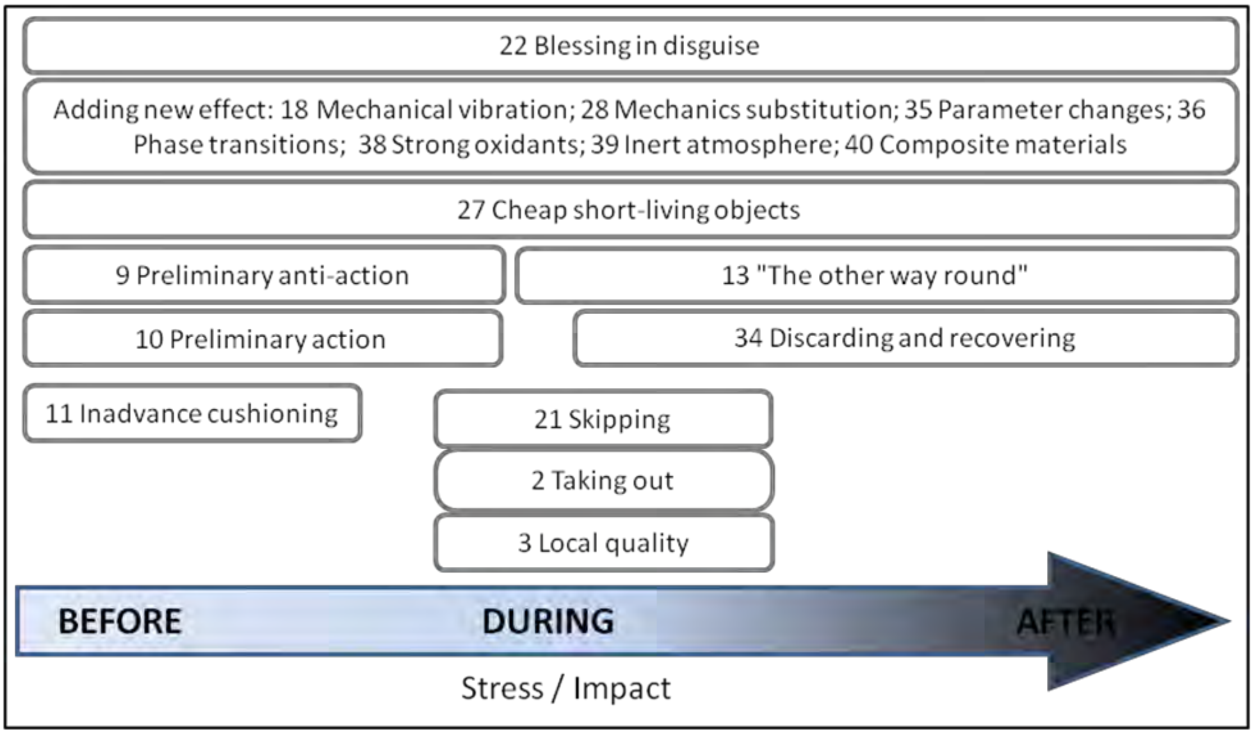

Fig. 6. Proposed schematic of applying Inventive Principles for developing heuristics

In addition to these Inventive principles, the authors consider Standard Solutions as a tool for developing heuristics. Specifically, standards of Class #1 "Building and Destruction of Substance-Fields" are appropriate for developing heuristics that can be used for diagnosing antifragility.

Standards of Class #5 "Standards on Application of Standards" can be used for enhancing solutions that meet the concept of antifragility

Why is this approach of combining known TRIZ tools effective?

- It leads to the following informative decision: developing antifragility can be done with TRIZ techniques or with combinations of such techniques.

- This approach is relatively simple. Heuristics can be created using well-known TRIZ tools.

What are the limitations of the proposed approach (i.e., combining known TRIZ tools)?

- There are a great number of potentially applicable principles and standards; however, it is not quite clear how they can be combined and applied:

  - In what sequence should they be applied?

  - How should they be combined?

  - To which part of the system/subsystem should they be applied?

- There are no statistically or empirically proven observations on selecting principles/standards and evaluating the efficiency of the selected tools.

- As Taleb mentions over and over, the antifragility of a system can be achieved at the expense of the fragility of its components. It is not clear from this how such techniques can be applied to engineering systems.

In conclusion, let us look briefly at the connection between other TRIZ techniques and the concept of system antifragility:

- Ideal Final Result (IFR) is one of the basic concepts in TRIZ. Antifragility can be considered an additional notion of IFR, or, antifragility can be IFR at a more advanced, higher level. That means, not only is "the result achieved by itself", but this result should be preserved and enhanced when the system is under exploitation. This is a novel problem statement that has not been articulated in TRIZ before.

- Utilization of Resources – among other general/universal resources (e.g., training/developing the immune system to resist many diseases, instead of taking a different medicine for each decease). It is an important task now to identify and group resources that are available for performing functions that have not been seen before.

- Trends of Engineering System Evolutions (TESE) - antifragility can be developed in the context of TESE. Specific mechanisms and sub-trends can be identified.

- Failure Anticipation Analysis (AFA) can be complimented with a new notion: what should be antifragile within the engineering system being analyzed? It is important that we are not trying to predict a potential impact/stress, but we are trying to identify strategies and heuristics for developing antifragility at different system levels.

5. Main results and conclusions

In this paper, the authors have demonstrated that the concept of antifragility can be a valuable, practical technique which can supplement TRIZ techniques developed for improving engineering systems. It is still necessary to make some clarification in terms of parameters, system level and time interval.

TRIZ tools are very applicable both in describing mechanisms of antifragility and in creating heuristics for developing antifragile systems.

The authors consider the next steps to be the development of more practical recommendations on applying TRIZ tools in connection with the concept of antifragility. In addition, some real case studies must also be developed.

Acknowledgements

We extend our sincere thanks to our colleagues who participated in discussions about TRIZ and Antifragility. Special thanks to Deborah Abramova who helped to make this paper sound literate in English.

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MPV-BASED ENGINEERING SYSTEM EVOLUTION

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Abstract

Trends of Engineering System Evolution (TESE) is a very important concept of TRIZ methodology. This tool makes it possible that we could predict the future. But when applying it in practical research & development projects, engineers have difficulties in two aspects: 1. It's not possible to predict which alternative will be dominating or more probable to "win" in the future; 2. The time frame for TESE prediction is too long that engineers feel it's too far away for product development projects. In this article, the author explored a different way of applying TESE. The author argues that the evolution should predict the future of a certain product or engineering system, instead of presenting different alternatives. Also, the evolution should present the competing directions and predict the probability about which direction would "win" in the future. So the author suggests that the market needs will drive the evolution directions. In previous literature, the author explored tools and methods to analyze and select MPVs, and MPV is an important tool for analyzing market needs. So the author suggest that the evolution should be organized based on MPVs and the TRIZ engineering system evolution principles. In this article, the author presented a new method through a case study. When we adopt this approach, the evolution trends will be more useful in predicting the future of a specific product, and thus is more applicable to product development practices.

Keywords: MPV; TESE; Evolutionary Tree

1. Introduction

Trends of Engineering System Evolution (TESE) is a very important concept of TRIZ methodology. Traditionally, there are nine laws of technical system evolution started from Altshuller [1]. Each of these laws plays different role at a given stage of its lifetime. The nine laws were explained in details by Salamatov [2].

In Modern TRIZ, there are nine engineering evolution principles, which has been explored in many aspects in many industries. In Sergei Ikovenko's course [3], these Trends of Engineering System Evolution are summarized in hierarchical order. See below figure.

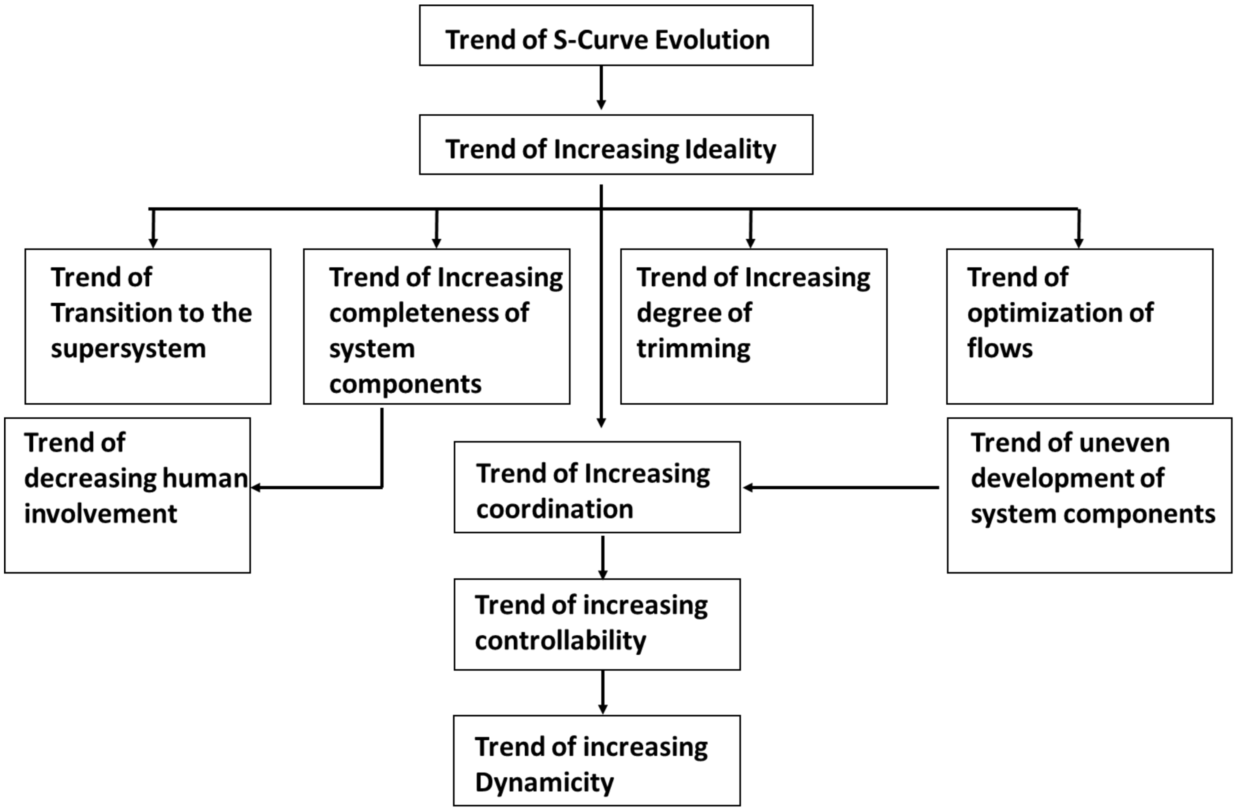

Fig. 1. Hierarchical layout of Trends of Engineering System Evolution

However, there is always controversy about whether TESE is applicable in the product development practices. One of the key challenge is that the customer need aspect of engineering system is not included in TESE. For example, after Apple introduced iPhone, all the users tend to buy a touch screen phone. When touch screen becomes a trend, product development practitioners pay attention to it when they plan for future new products, but there is no this trend in TESE.

2. Challenges and Assumptions

Engineering system evolution principles are not easy to use it in practice. It is not quite applicable if we want to predict the future, because when we use these principles, we could easily list different future alternatives, but it's not straightforward for predicting the future products. If we apply engineering evolution principles to a bicycle, it's easy to list the future options, for example, following the trend of increasing completeness of system components, there is the version of electrical bicycle; following the trend of increasing controllability, there is the version of better control of saddle. However, there are different component within a bicycle, which one will evolve faster than others are? On the other hand, will they evolve at the same speed? If we pick one subsystem, for example, the saddle of a bicycle, which trend will it follow? TESE did not answer these questions. The ultimate question for engineers is what will be the most successful/dominating product in the market in the coming years, but TESE does not answer this question.

The second challenge comes from the scope of a system. When we talk about S-Curve of bicycle, we could refer to S-Curve of bicycle as a category, we could also refer to a certain type of bicycle, e.g. mountain bike; even we could refer to a more specific brand, e.g. Giant. When we talk about the S-Curve of the generic bicycle, then it refers to the whole history of bicycle shown as below.

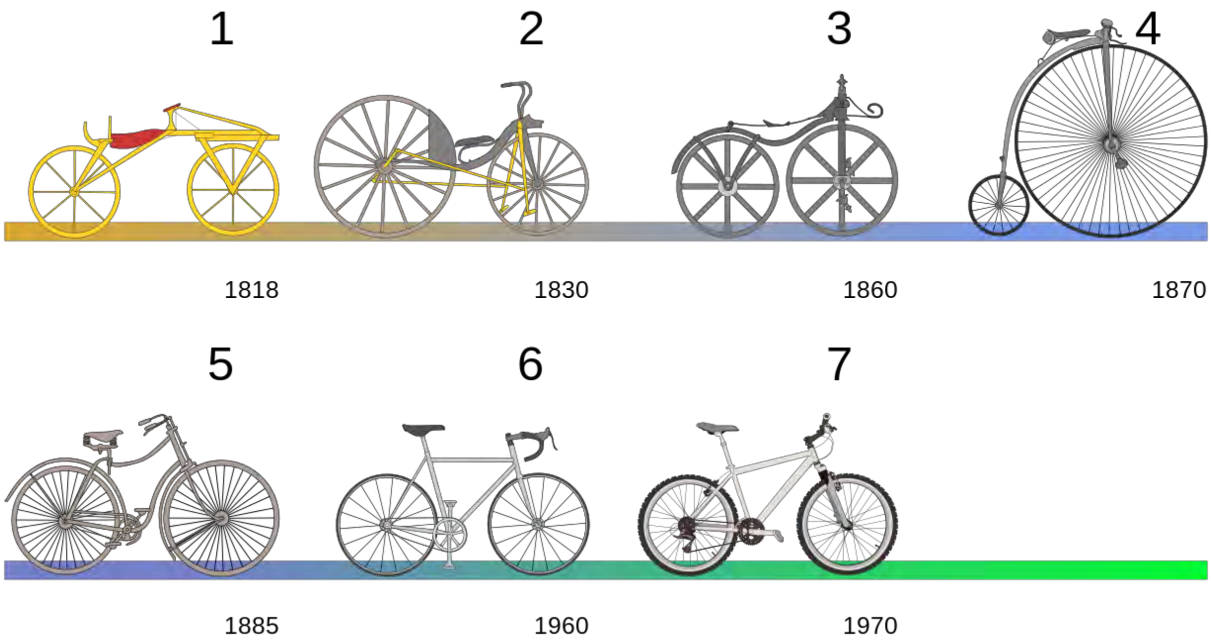

Fig. 2. Evolution of Bicycle, picture excerpted from wikipedia.

But the history and future of a bicycle does not make much sense for a product designer from a specific company such as Giant, because the designer's objective is to launch a new product within one year, rather than 30 years in the future.

Shpakovsky[4] suggests that we should use Evolutionary Tree to predict the future. Which is more applicable in practice because of two reasons. Firstly, the Evolutionary Tree pick a single function as a subject of evolution. For example, a bicycle has different functions, but if we want to predict the future of bicycle, we have to pick one function of bicycle, e. g. moving people. Then we could start to predict the different products that will be serving the purpose of moving people. Secondly, The Evolutionary Tree combine all principles together, so that people could apply the principles consistently.

In this article, we would like to build on the previous literature and further improve the way we predict the future.

3. MPV-based Engineering System Evolution

The author assumes that for any product or technical system, the major driving force comes from outside. The macro trends and market need trends are the two categories of outside driving forces that have significant impact to engineering system evolution. For example, one of the most important driving forces of products' evolution comes from changing customer needs. In previous research, Yezersky already explored how to combine system engineering and customer needs [5] to foresee the future products and services, and pointed out that "solving the right problem" is much more important than "solving the problem right".

This article takes a further step to link the engineering system evolution principles with eh customer needs.

Main Parameter of Value (MPV) is a description of the parameter(s) that contribute most to Customer Value. In a previous article, the author suggested a Perceived Value-Function-Parameter model to define MPV [6]. As MPV is the main parameter of value, and the engineering system is always evolving towards ideality, by definition, Engineering System Evolution should be development towards maximal MPV.

Because MPV is not a fixed parameter, and it could be very different in different stages of a product. So it is important to define the MPV with a systematic approach. The previous paper covered quite a bit about how to define MPV[6].

Overall, MPV-based Engineering System Evolution is quite different with TESE, and here is a comparison between TESE and MPV- based Engineering System Evolution.

Table 1.

Comparison between Trends of Engineering System Evolution and MPV-based Engineering System Evolution

	TESE	MPV-based Engineering System Evolution
Objective	Predict the future possible alternatives of a certain engineering system	Predict the exact roadmap of a product
Time Frame	Very long term	Relatively short term
Basic Assumption	The driving force of evolution comes from inside of the engineering system	The driving force of evolution comes from both inside and outside of the engineering system
Methodology	Collect information of current products, and then come up with new ideas	Collect information of the macro environment and market, define MPV, and then predict future evolution based on MPV
Direction of evolution	Huge diversity	Limited diversity
Application scenario	Ideation about future technology	Technology Roadmap

In the following part of this paper, the author uses a case study to explain the key concepts.

4. Background: Haier Electrical Water Heater

Haier is a famous home appliance manufacturer. In the electrical water heater market, Haier kept in top 3 brands in the past years. In this case study, the author participated as an innovation expert to teach the team how to define MPV and how to plan the future product roadmap.

10 years ago, the mainstream product value proposition in the market is about safety and price; 5 years ago, the mainstream value proposition is about energy-saving and fast heating; and

Haier was always keeping abreast of the best. 3 years ago, with the rise of health awareness, consumers began to pay attention to bathing water quality, so different players launched different products. Haier also had its "Clean Water Bathing" series products. In 2015, a competitor introduced a new product concept, i.e. “Running water brings you good health" and occupied part of the market share. “Running Water” is not a competitive technical solution, but a marketing concept. In order to promote the company's brand position in the high-end water heater market and to build a fence over competitors, Haier hopes to introduce a best-selling high-end electrical water heater. The challenge is mainly about how to create an innovative product and how to plan the future products.

5. MPV of electrical water heater

In a previous article, the author suggested a Perceived Value-Function-Parameter model for MPV [6]. Perceived value is the collection of benefits that customer/consumer gets in return for the financial investment in a consumption behaviour [7].

After we identify perceived value, then we could start to define the MPV. In this case, we started from targeting the right consumer group and carry out research about their perceived values.

After careful studies of the macro market environment, we found that several macro trends that will most probably influence each other and have huge impact to the market: Consumption Upgrade (From Quantity to Quality); Increasing Awareness of Health; More kids due to the state policy; The rising power of women.

Because women will play a major role in family budget decision, and women make quite a lot of decisions based on babies, especially the healthy growth of babies. For them, especially the younger group, they are willing to pay more money for better quality.

Based on the analysis, the prediction is that the future key battlefield will be the middle and high-end market, and women aged 25-35 will be the most important consumer group for electrical water heater market.

Then we started to study the group of young women aged 25-35, and we found that they have something in common. Below is a description of the persona of this group:

Basic situation: Mrs. Ho is a 30-year-old white-collar female with a bachelor degree, who has a 3-year-old boy. The annual income of her family is 20W in RMB.

Character: Mrs. Ho is curious about new things. She has a group of girlfriends and they exchange a variety of information every day. She has very good relationship with her husband and has a happy family. She makes most of consumption decisions for her family.

Behaviour characteristics: Mrs. Ho loves her family and she consider herself as a manager of family health and hygiene. Therefore, she has purchased many household electrical appliances, such as air purifiers, disinfection cabinet, water kettle and so on. She pays attention to parenting news and take a great care of her baby boy. In addition, she pursues the quality of life, but she has very limited time for that.

Then we started to visit consumer family and observe how they use water heater. Below is a little story I have been experienced with a consumer.

This lady is a 28-year-old housewife with a 3-year-old boy. She is slim, and keeps fit regularly. After we arrived at her home, we started to chat about lifestyle and using water heater. She does not enjoy bathing at home, and in most occasions, she takes bath in gym. However, she has to help his boy take a bath every day. When I asked her "What is a good electrical water heater in your mind?", Her answer sounds quite strange for me. She said, "If there will be no problem even when we drink the water, then it's a good water heater." I was quite curious, "Why do you drink the water from water heater?" "Oh, no, no, no, I don't drink it. Because my baby boy play with and splash water when bathing, so water will go into his mouth and eyes. If the water is edible, then I don't need to worry about his health."

At this moment, I soon understand what is most important for women about water heater: water quality that keeps them free of worry. Moreover, this story repeat repeatedly in consumer home visits.

Then we prepared some product concept and communicated the value proposition of "drinking level water quality" with more than 30 target consumers and validated this finding.

Fig. 3. Product Concept Produced After Market Research

So here we found out a perceived value of the female consumers: water quality that keeps them free of worry. However, when we talk about water quality, consumers cannot tell what is good, and what is bad. So we did a further study to understand what part of water quality could be perceived by consumers. In water, there is chlorine, bacteria, heavy metal ion, calcium ion, magnesium ion, etc. We found that what consumers could tell most about the water quality is scale. Because people use water kettle every day, and they know about scale, they can see it on the shower (See below figure). But they could not tell bacteria, chlorine, and heavy metal ion.

Fig. 4. Scale on shower perceived by consumers.

So we pick the function of de-scaling as a key function and the amount of scale in water as a key parameter. Then we did a further study with consumer to verify whether this is accepted by them. We did a comparison study with 50 consumers. We compared the previous product concept and the new product concept and confirmed that de-scaling is a perceived value.

6. Evolution Tree based on Key parameter.

6.1 Key Functions and Key Parameters.

After we confirmed de-scaling as a key function for electrical water heater, we started to study the key parameters and pick the amount of scale deposit as the MPV. In previous literature, the author suggested a model to map MPV on S-Curve [6]. When we consider different parameters, we could map them on the S-Curve. See the parameters in below figure.

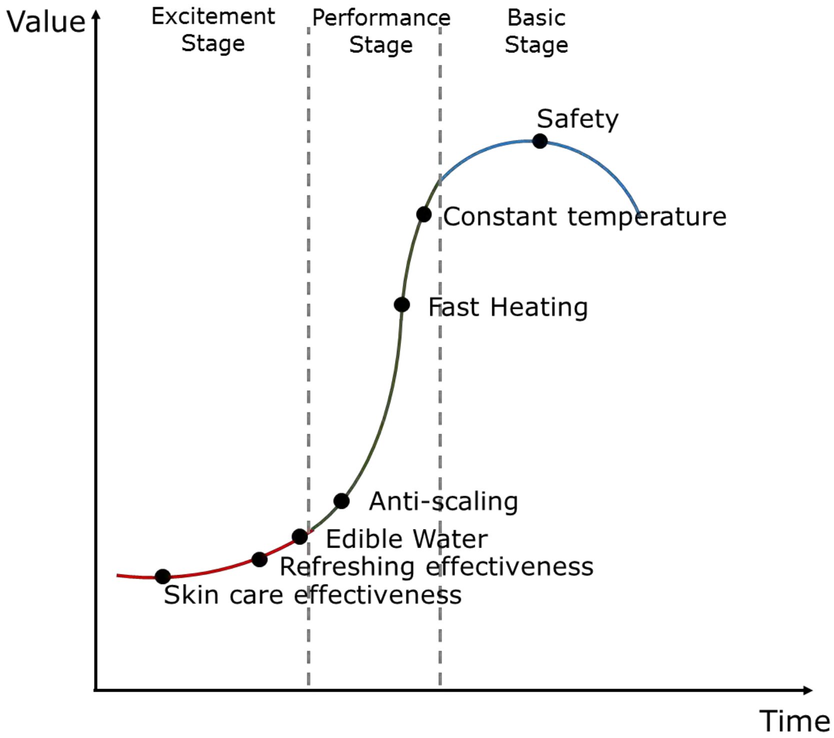

Fig. 5. Parameter of Perceived Value Mapped on S-Curve

Among the different parameters, anti-scaling, fast heating and constant temperature are the main functions and parameters. As fasting heating and constant temperature are close to mature stage, we pick anti-scaling as MPV and predict the future of a water heater based on it.

6.2 Evolution of Operation Principle.

Operation principle refers to the key technical framework for an engineering system, i. e. how the engineering system works as a whole does.

After we pick the main function and main parameter, then we start to analyse what could be the operation principle for de-scaling. We performed a Cause-Effect Chain Analysis on scale as below. The key factors related to scale include decreasing temperature, decreasing concentration of calcium ion and magnesium ion, reducing dissolved carbon dioxide, and removing existing scale.

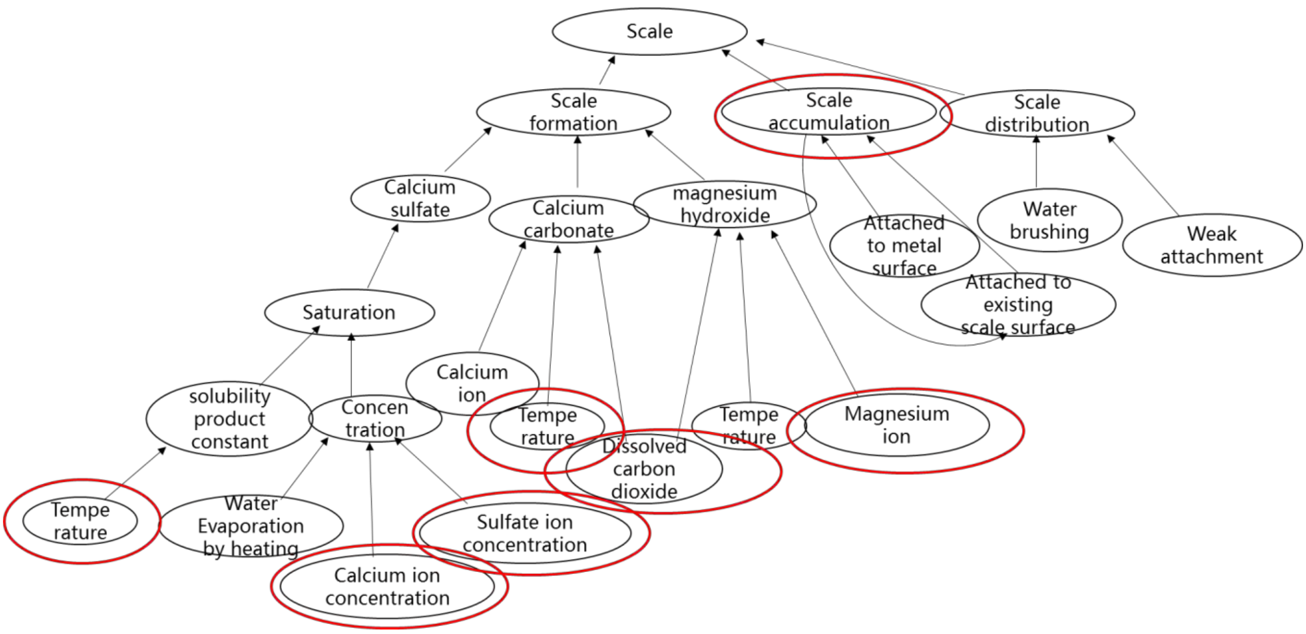

Fig. 6. Cause-Effect Chain Analysis of Scale

Then we map the possible operation principles on a tree format as shown in below figure.

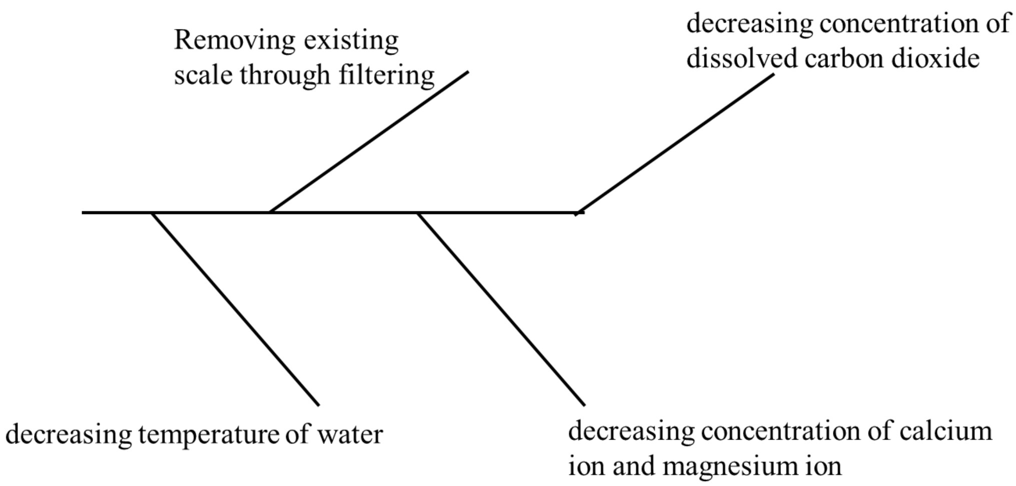

Fig. 7. Tree-shape format of operation principles

Then we further explored one of the operation principles because we think this one will be dominating operation principle in the middle term. To make it clear, we applied the evolution principle of segmentation as explained in Shpakovsky's book[4]. See below figure 8 of the evolution trend.

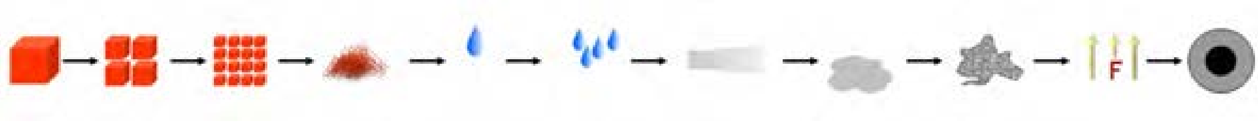

Fig. 8. Trend of Segmentation, excerpted from Evolutionary Tree[4]

Based on the trend of segmentation, we expanded figure 7 into a more detailed version as shown below.

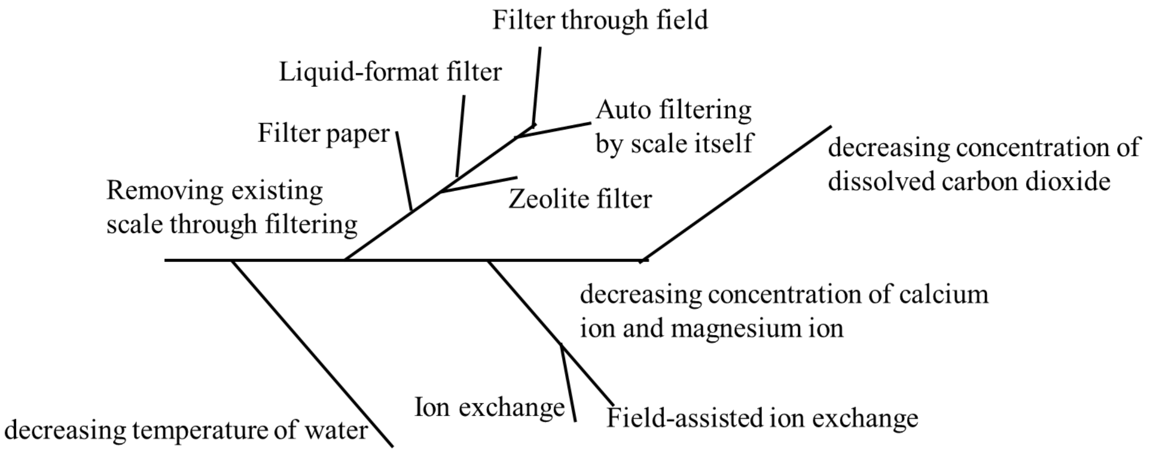

Fig. 9. Expanded Tree-shape format of operation principles

6.3 Evolution within Operation Principle.

Within a certain operation principle, we could further expanded the evolution according to the method Shpakovsky suggested in his book [4].

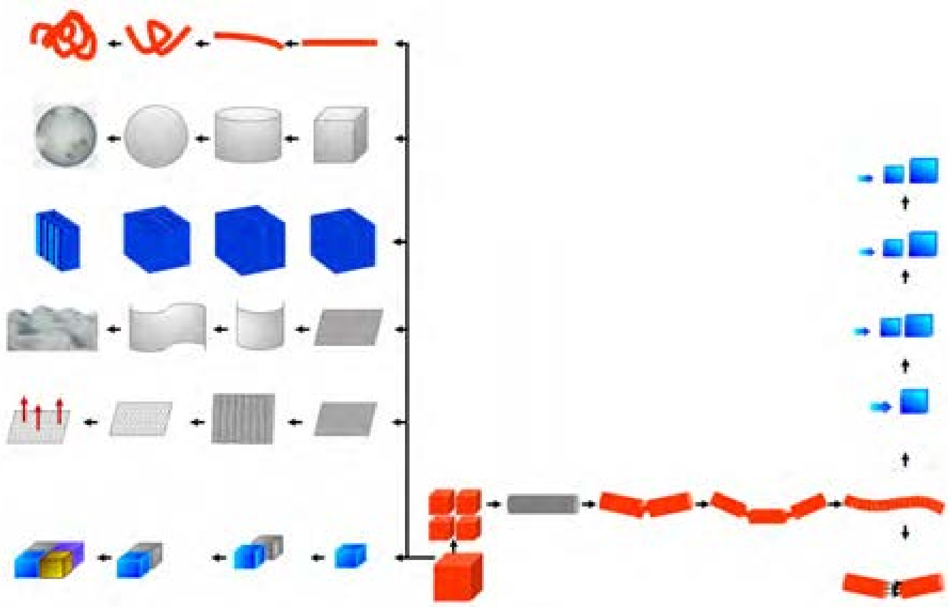

Fig. 10. Evolutionary Tree, excerpted from Evolutionary Tree [4]

We chose the filter paper to further expand the evolution and applied the other evolution trends. See below figure.

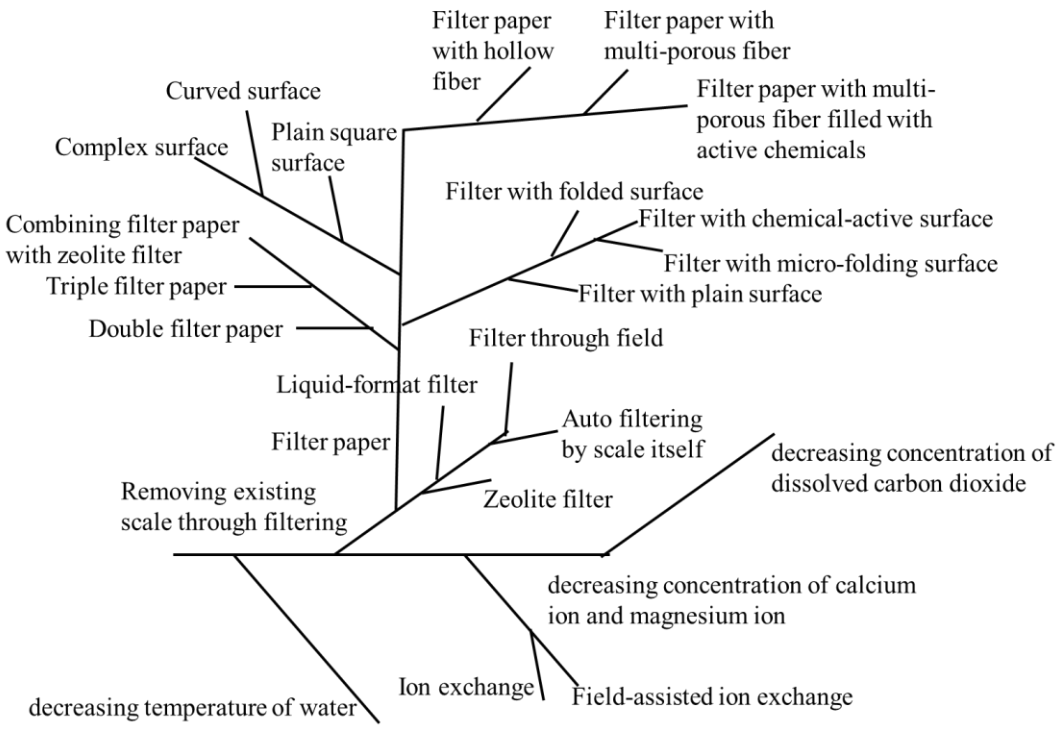

Fig. 11. Tree-shape format of evolution for removing existing scale through filtering

6.4 Overall evolution map

Since we have predict one function/parameter in detail, the next step is to predict the evolution for all the functions/parameters. We combined figure 5 and figure 11, and created a complex map. It is a bit messy, but it better reflect the essence of engineering system evolution in practical product roadmap planning.

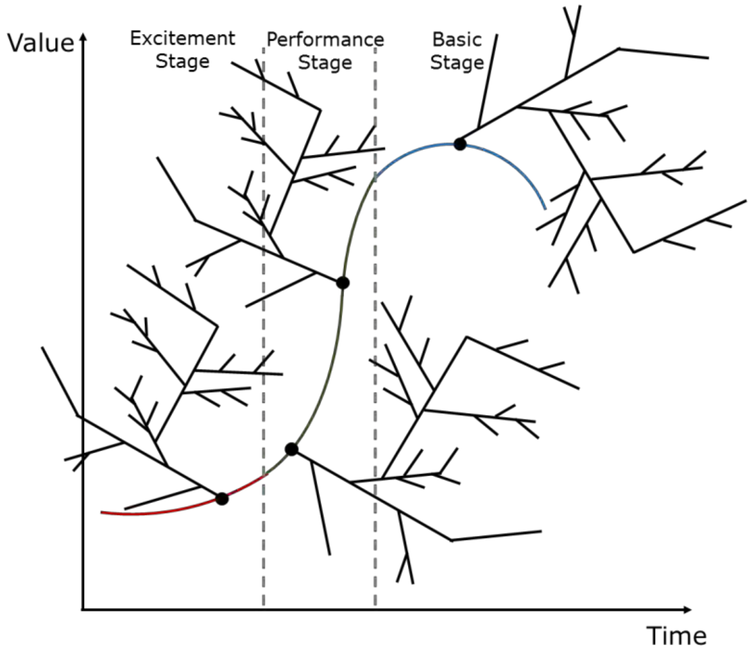

Fig. 12. Overall engineering system evolution map

6.5 Turning Evolution map to product development roadmap.

Since we have formulated the tree-shape evolution map, we could start to further develop the product development roadmap. Internal discussion sessions were organized to generate ideas based on the evolution map and prioritize based on feasibility and strategic focus. Then a blueprint of projects over timeline is laid out. For confidentiality concerns, the details are not covered in this paper.

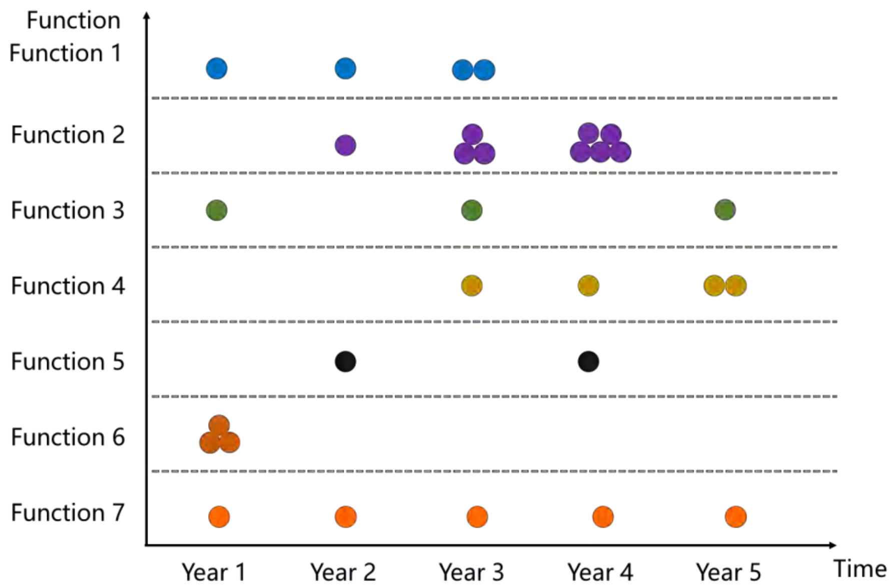

Fig. 13. Technology roadmap based on function

7. Business Results

Then we developed a product featured with 80% scale reduction, and the value proposition of this product is “clean water that protect your baby from scale.” Even if the water split into the baby’s mouth or eyes accidently, the mom will not worry about it. See below poster that convey the message.

Fig. 14. Advertisement that convey the value proposition of the product

The product was launched to the market on December 18, 2016. It is a great high-end brand selling at the price of 5000-6000 RMB, while the average price of this market is 1500-2000 RMB. Because the product is targeting the MPV, it was well received by the market. In the first three months, it was sold more than ten thousand units. Compared with competitor, this product is the only one that targets the mom of babies. With Haier’s already very good reputation in the market, it further enhanced the brand image. Also, because we have planned for future technologies based on engineering system evolution, it has opened up a new path for follow-up product strategy, and thus is very good for future competitive advantage.

8. Discussion.

In this case study, we explained a step-by-step process of MPV-based engineering system evolution, which is more systematic and practical for product development engineers. We identified MPV by consumer research, and predict the engineering system in two stages. In the first stage, we predict the future for operation principle; and in the second stage, we predict the future within operation principle. This makes the work of engineering system evolution more practical.

However, there are a few issues that need to be addressed in future research. The first question is about whether MPV is the driving force for evolution. The author safely assumes that the engineering system evolution develops towards better customer value, but we need to further validate whether it’s universally applicable. The second question is about the effectiveness of identifying MPV. Because we used qualitative market research methods to identify MPV, it’s not scientific evidence. So how to identify MPV is still a focus area for future research. Finally, we followed the previous research when we apply the specific evolution trends. There is no clear-cut criteria for judging whether we have discovered all the evolution trends, and there is no guideline for which trend we should follow at which point. Future research will focus on how to make the process even more systematic and practical.

In conclusion, this paper introduced a new way to perform engineering system evolution analysis based on MPV identification. MPV-based engineering system evolution makes better sense for product developers, and it's more applicable for product development roadmapping.

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NATURE AS A SOURCE OF FUNCTION-LEADING AREAS FOR FOS-DERIVED SOLUTIONS

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Abstract

Rather than developing completely novel solutions, it is now common practice to identify and adapt technologies that already work in other, sometimes very remote, industries. Function-Oriented Search (FOS) is a tool in modern TRIZ that allows navigating between different industries, and consequently selecting the best available technologies to perform the desired function. One general recommendation suggested by FOS is to look at how the required function is performed in Nature. So far, however, no specific recommendation has been developed on how to identify the function-leading areas in Nature. To address this, we propose a soft algorithm: FOS in Nature. This algorithm helps identify the function-leading areas in Nature, not only at the macro-level (i.e. at the level of entire organisms or their organs), but at the micro-level as well (i.e. at the level of living cells, cell components and biomolecules). A few case studies are presented in this paper to demonstrate the proposed algorithm.

Keywords: Function-Oriented Search, Nature, algorithm, biomimetic design, biomimetics, biomimicry.

1. Introduction

Function-Oriented Search (FOS) is one of the most powerful problem-solving tools in TRIZ today. The main idea of FOS is to adapt existing technologies from remote areas of science and engineering to solve a specific problem in some area that needs innovation. A solution developed with FOS is easy to accept because, by definition, it is an existing technology that already works in a function-leading area, although there are adaptation problems to be addressed. Moreover, as FOS brings solutions from remote areas of science and engineering, it gives access to the scientific and technical knowledge of the entire world. So, FOS is a practical, efficient approach to open innovation.

One of the possible function-leading areas in FOS is Nature, which, however, is quite unlike other function-leading areas of the technosphere. This is, first, because engineers are generally not as comfortable navigating within subareas of Nature. Furthermore, despite the detailed character of the current FOS algorithm, there are still very few recommendations about how to identify the function-leading areas and corresponding technologies - which is even more problematic for engineers practicing FOS in Nature. And finally, in contrast to the technosphere, Nature does not usually provide ready, existing technologies to adapt, but offers only natural solutions for inspiration. These three issues may make the identification and adaptation of the most interesting natural solutions quite difficult for practitioners of FOS.

The present article covers a substantial part of a work-in-progress, and suggests ways of tackling the aforementioned issues.

2. TRIZ-based biomimetic design approaches

Nature has been a source of inspiration for inventors for eons, well before the advent of TRIZ, and certainly long before the word bionics (and later, biomimetics and biomimicry) was coined. One example of a biomimetic invention is the battering ram used in ancient Greece, inspired by the ram's forehead [1].

Altshuller once was surprised by the scarcity of bionic inventions, and proposed in step 8 of ARIZ-71 the paleobionics approach, i.e. to look first at old Nature "patents", for they are considered simpler and more effective [2], which may or may not be the case. Interestingly, the latest official version of ARIZ, ARIZ-85C, omits this recommendation.

A long time after Altshuller's preliminary work, several authors have proposed TRIZ-based or TRIZ-related biomimetic design approaches. A modern TRIZ approach is to apply FOS [3] [4] and consider Nature as a possible function-leading area; however, no specific recommendation is given on how to identify function-leading areas within Nature.

Attempts were made to expand the Altshuller matrix into the so-called Matrix 2003 (and later into Matrix 2010), so as to integrate modern technology findings [5]. Initially it was aimed at building a new contradiction matrix based on identified biological solutions; however, this project was later abandoned when it turned out that the 48 parameters of Matrix 2003 were sufficient to describe biological strategies, and that 95% of the solutions developed by Nature matched the inventive principles suggested by the cells of Matrix 2003 [6].

Other authors proposed a new 6x6 matrix (the 6 considered parameters are: substance, structure, time, space, energy/field and information/regulation) based on biological solutions, but this new matrix keeps the 40 inventive principles unchanged. This so-called PRIZM matrix shows a correlation factor between the respective biological and technological solutions to contradictions of only 12%. Nevertheless, from a practical point of view this matrix suffers the same disadvantages as the Altshuller matrix, including its general and abstract aspects.

Later, Bogatyrev *et al.* [7] proposed new biology inspired trends for developing current technologies with the aim of making those technologies eco-friendly. This interesting approach still needs a detailed description backed up by biological and technological examples to make it fully instrumental.

A comparison between the Altshuller matrix and biomimetic design has been made by Currie *et al.* [8] based on a specific technological challenge, i.e. the design of a proton exchange membrane fuel cell. Although the authors considered only one example, they concluded that biomimetic design and TRIZ seem to yield comparable results.

Another work defines a network of relationships between bio-inspired geometrical structures and principles (symmetry, spirals, undulations, ramifications…), functions, eco-principles, and the Altshuller matrix parameters and inventive principles from TRIZ. Nevertheless, it is questionable whether this approach provides more benefit than the Altshuller matrix.

In their study, Baldossu *et al.* [10] have recommended improving the usability of biomimetic databases (those of the Biomimicry Institute [9] being the most famous), which show how different natural organisms tackle different challenges, by re-indexing them using an OTSM-TRIZ functional model (function carrier – action – function object). This approach could be instrumental, but such a complete, re-indexed biomimetic database does not yet exist.

Weaver *et al.* [11] propose to illustrate both principles for the resolution of physical contradictions and inventive principles with biological examples in addition to technological examples – for better inspiration.

In order to reduce the identification of biological strategies for a given technological challenge, Vandevenne *et al.* [12] have proposed an automatized biomimetic design process. Their process determines product features based on a patent database, and then matches those with organism features determined from a biological database, finally delivering biological solutions. The main drawback to this approach is that the product features do not necessarily relate to the key problems that have to be solved.

Hu [13] has made an attempt to combine biomimicry and TRIZ. He suggested finding all the contradictions linked to a specific problem and determining all the inventive principles that relate to them. Then, using these principles, the problem solver needs to find Nature's "solutions" to similar problems in a biomimetic database.

The most accomplished study so far, by Bogatyrev *et al.* [14], recognizes and explains the complex and empirical nature of biomimetic design; introduces four TRIZ-derived axioms (simplification, interpretation, ideal result and contradictions), and, finally, proposes a 6-stage biomimetic algorithm which attempts to overcome the issues mentioned in the introduction. This algorithm can help when no engineering prototype exists (e.g. for the artificial cilia project executed by Bogatyrev *et al.*). It is well structured and uses sound concepts, such as main function, environment, time and size scales. Some aspects of the algorithm, however, remain unclear (for example, which TRIZ tools should be used for the problem definition?), and too many TRIZ tools must be used, including contradictions, nine-windows tool and the inventive principles, which may make it very complex to apply.

Kamps *et al.* [15] have developed a TRIZ-based biomimetic part-design method for optimizing laser additive manufacturing (LAM) for a titanium alloy reamer. The technological feasibility of a biological solution is assessed to see whether this biological solution matches an inventive principle and the corresponding pair of conflicting parameters from the Altshuller matrix. This method of assessment seems rather constraining.

In the most recent approach by Vincent [16], a database of biological examples has been built where the identified principles that solve any pair of engineering contradictions are sub-classes of the well-known 40 inventive principles. For example, the principle "conversion to dynamics" is further split into 5 sub-principles, including "reduce shock", and the sub-principles might be further split into sub-sub-principles. Interestingly, this database can also be filled with biomimetic case studies. This biomimetic design approach gives the designer a wide set of biological strategies. So, the instrumentality of this approach is higher than that of many others, but yet it is limited by the representative character of the examples studied.

In conclusion, most of the TRIZ-based or TRIZ-related biomimetic design approaches rely either on the Altshuller matrix and/or inventive principles, or on its simplified or refined versions. Also, biology inspired technological trends by Bogatyrev *et al.* [7] might have potential, but they are not yet instrumental.

None of the authors mentioned above, nor any others, have yet developed FOS in Nature. If, however, FOS in Nature can address the issues mentioned in the introduction, it would become an instrumental approach in state-of-the-art TRIZ.

3. Biomimetic design approaches and their partial convergence with TRIZ

Today biomimetic design (or its equivalents) is an active field of science and a recognized design method. Usually two complementary sides of this discipline are considered: the problem-driven and the solution-driven approaches [17]. In the present paper we focus on the former approach.

The problem-driven approach has yielded numerous products, materials, manufacturing processes, robots, optimization methods and algorithms; its fields of applications has expanded to include sports, building, transport, software, etc. This can be seen from the growth in the number of biologically inspired design patents [17]. Nevertheless, the method should be improved to make it more systematic [18].

The power and limits of different problem-driven biomimetic design approaches introduced in papers [17 - 20] have been investigated by some authors, who observe the following similarities with some modern TRIZ tools:

• a functional definition of the problem [17];

• the identification of contradictory functions [17] [19] (e.g. moss should have a big surface area to collect sunlight, but moss should have a small surface area to retain water);

• the extraction of the biological principle [17] and the principle application or analogical transfer resembles TRIZ Feature Transfer tool;

• the search for variations [17] is equivalent to the search for different systems using different principles, i.e. TRIZ Benchmarking;

• broadening the search when reframing the initial engineering problem into biological terms [17], or the search for hypernyms [19], is similar to the function generalization in FOS;

• interviewing biology experts [19] is similar to interviewing function-leading area experts in FOS;

• the search for champion adapters [17], based on the assumption that "extreme habitats provide survival challenges that leverage innovative design solutions" [21], is similar to the identification of leading areas in FOS, for which the fulfilling of the generalized function is a matter of life and death.

Some aspects of biomimetic design not related to TRIZ should also be noted, e.g.:

• the similarity of environment between the initial engineering problem and potential biological solution (e.g., the lunar LIDAR at risk of failure because of fine regolith particles is similar to the environment of some marine bivalves) [19];

• the consideration of different size scales when searching for biological solutions [19].

These observations show that there are several elements of biomimetic design that are similar to classical or modern TRIZ concepts and tools, and a few that are not. Some of these elements, whether or not similar to TRIZ, can be used in the development of FOS in Nature, as will be shown below.

4. The algorithm of FOS in Nature

The FOS algorithm was proposed by Simon Litvin [3] and consists of 11 consecutive steps:

1. Identify the target main parameter of value (MPV) to be improved.

2. Identify the target physical parameter to be improved in order to address the MPV.

3. Identify the key problem to be solved in order to improve MPV.

4. Articulate the specific function to be performed in order to solve the key problem.

5. Formulate the required parameters/conditions for performing the function.

6. Generalize the function by an object and action of function.

7. Identify the function-leading areas (FLA).

8. Identify most effective technologies within the FLA which perform the same or a similar function.

9. Select the technology that is most suitable to perform the desired function based on the requirements and constraints (primarily MPVs) of the initial innovation area.

10. Identify the initial level of similarity factor (SF) between the conditions of performing the function in the selected technology and the initial innovation situation.

11. Identify and solve the adaptation problems required to increase SF in order to ensure effective implementation of the selected technology.

Not all of the above steps need be employed in practice. For example:

1.If a set of target MPVs has already been defined at the beginning of the project, and a key problem has already been defined in functional terms, then the FOS algorithm starts at step 5.

2. If a set of target MPVs has not been defined, then the FOS algorithm starts from step 1; in that case, the output of FOS at the end of step 8 can be used for Benchmarking in the analytical stage of the project.

Whatever the case, steps 7 and 8 are clearly those that should always be used in TRIZ projects; however, they have to be adapted for FOS in Nature. We then propose the following modifications for these steps:

7. Identify in which natural environments the generalized object of the generalized function can be found, preferably at an extreme concentration level (either huge concentrations or minute concentrations), all the time, usually, or rarely. In fact, any relevant parameter (e.g., pressure, speed, contamination) of the generalized object should be considered at an extreme value. Optionally, any component, also generalized, that influences the generalized function can help identify the leading area in Nature; i.e. most promising natural environments where potential solutions can be found. It should be noted that these natural environments may even be living beings.

8.1. Identify which non-biological natural phenomena perform the same or similar generalized function within these natural environments. Possibly this function is critical for the survival of some living beings (threat or opportunity).

8.2. Identify which biocomponents or their products perform the same or similar generalized function within these natural environments. Biocomponents may be any type of life form: animals, plants, fungi, bacteria, or viruses. First of all, look at where this function is critical for their survival (threat or opportunity). Consider biocomponents at any size, from molecule to biosphere.

8.3. If the key problem is expressed in the form of a contradiction, identify which biocomponents have apparently "faced" and "solved" the same or a similar contradiction, while performing the same or similar generalized function.

8.4. Extract the physical/ chemical/ geometrical feature(s) from the identified non-biological natural phenomena.

8.5. Extract the biological feature(s) from the identified biocomponents.

8.6. Transform the biological feature(s) into physical/ chemical/ geometrical/ information transfer/ organizational feature(s).

8.7. Transfer the extracted feature(s) onto the engineering system/ component at hand.

We denote biocomponents as any part of a living being (organ, cell, etc.), any entire living being or any group of living beings.

5. Test of the algorithm of FOS in Nature on some case studies

5.1. Test of the algorithm on a macro-level case study: Mercedes biomimetic car

Let us first consider the well-known case study of a Mercedes biomimetic car [22]. In a retrospective approach, let us see how the proposed algorithm could have been applied to come up with this concept, and maybe other concepts. In 1996, Mercedes engineers were trying to design a concept car with new aerodynamics. The application of FOS in Nature could have been as follows:

1. The MPV "energy/fuel consumption of a car" should be decreased.

2. The target physical parameter "air drag coefficient of a car" should be decreased.

3. Key problem: how to decrease the drag coefficient of a car?

4. Specific function: the car directs air.

5. Required parameter: the front of the car is short – e.g. so as to park easily in cities - and has a relatively high cross section – so as to transport a sufficient number of passengers.

6. Generalized function: to direct fluid.

7. Fluids that are available "in high concentration" (which may be interpreted in this specific case as high mass density per volume unit) in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, fish and aquatic mammals, birds, reptiles, cephalopods can be selected as leading areas.

8.1. This step suggests searching for rocks close to the sea surface that have been eroded by water resulting in a shape providing minimal drag.

8.2. So as to match the required parameter, these animals should have a short front. We identify the female yellow boxfish, the bullhead shark, the beluga and the sea iguana (see Fig. 1).

8.3. It is probable that in addition to the female yellow boxfish, all the identified animals have "faced" and "solved" the contradiction between large and high front and "direct water" with a low drag coefficient, as they are all predators. The initial key problem could have been expressed as a contradiction.

8.7. In this particular case, the biological feature is easy to transfer to the front of the car because it is (or at least it seems to be) purely geometrical. In practice, one obtains several geometrical options for the targeted concept car. Note that the boxfish has a drag coefficient of a mere 0.06, while a good, aerodynamically designed car has about 0.26 [22].

Mercedes designers created a new vehicle concept based on the female yellow boxfish. The final design had a very unusual shape for a car (see Fig. 2). Tests proved that this shape provides one of the lowest drag coefficients ever tested. However, as was shown above, other prototypes from Nature are available for the biomimetic design of some air or even water transport vehicles.

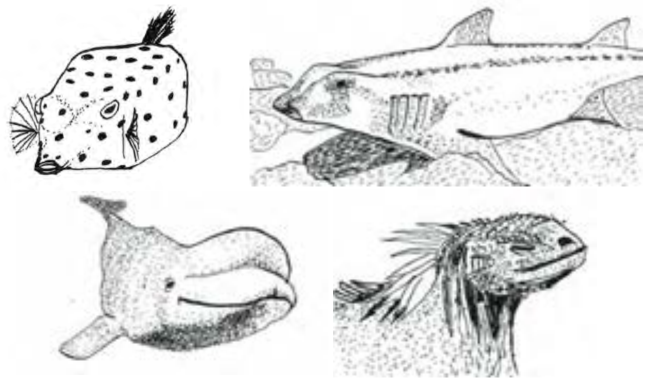

Fig. 1. Composite drawing of several aquatic animals with large and short front (female boxfish, bullhead shark, beluga, marine iguana)

Fig. 2. Mercedes biomimetic concept vehicle based on the female yellow boxfish [22]

5.2. Test of the algorithm on a partial macro-level case study: dental mirror

The problem proposed for this case study is the usual dental mirror that gets contaminated quickly while the dentist drills a tooth. It is necessary to avoid any heat that is detrimental to the tooth pulp; therefore the drill is cooled by a water jet. Drilling readily sprays water droplets and minute tooth residues onto the dental mirror. One efficient, commercial solution is a continuously rotating mirror [23]: the water droplets and residues are removed from the mirror by centrifugal forces. Applying the usual FOS [3] to this problem allows identifying some ideas based on hydrophobic coatings, on hydrophilic coatings, and on some other technologies. In this paper, a biomimetic, passive solution is considered. An application of the algorithm of FOS in Nature starting from Step 4 is as follows:

4. The external part of the dental mirror collects water droplets.

5. The mirror surface should retain its reflecting function, no contamination on the surface is allowed.

6. Generalized function: to collect fluid droplets.

7. A fluid that can be found in extremely fine "concentrations" is water/ fog in deserts, and in heavy "concentrations", again water, during occasional strong rains, also in dry areas. For example, plants, reptiles and insects from the desert can be selected as leading areas.

8.2. Some animals and plants harvest water from occasional fog in deserts (see Fig. 3): a long-legged Namib beetle [24], the Namib dune bushman grass [25], and a cactus from the Chihuahua desert [26]. The Texas horned lizard collects water from occasional rain [27]. And the list goes on.

Fig. 3. Composite drawing of two animals and a plant harvesting water

8.5 and 8.6. A complete study of the different physical or chemical features exhibited by those natural prototypes that can direct fluid droplets is beyond the scope of the present article. Nevertheless, the following physical features can be identified: a combination of hydrophilic and hydrophobic zones; capillarity effects with open grooves; property gradients between water harvesting zone and consumption zone.

8.7. It would be necessary to adapt some of the identified features. For example, bumps and grooves and other three-dimensional arrangements are apparently not compatible with the two-dimensional structure of the dental mirror. The rest is left to the reader, who may possibly come up with some interesting solutions.

5.3. Test of the algorithm on a micro-level case study: micro- and nanomechanical systems

This case study relates to reducing friction in micro- and nanomechanical systems (MEMS/NEMS). The problem is that regular lubricants cannot be used if the size of the lubricated parts is small because capillary, electrostatic, van der Waals and chemical forces make these lubricants adhere to the parts and fill all microgaps between the parts.

Therefore, in order to reduce friction in MEMS/NEMS it is necessary to create hydrophobic surfaces with a low friction coefficient and small contact area.

Since the MPV and key problem have already been identified, we will start with step 5 of the proposed algorithm.

5. Required parameters: high hydrophobicity, low friction coefficient, small contact area.

6. Generalized function that provides hydrophobicity: to direct (repel) fluid.

7. Fluids that are available "in high concentration" in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, aquatic plants, animals and birds can be selected as leading areas.

8.1. This step suggests looking for natural, non-biological hydrophobic objects.

8.2. This could be aquatic plants, mammal skins and bird feathers that repel water. For example, duck and goose feathers as well as lotus leaves are hydrophobic.

8.3. In this case study we do not express the key problem as a contradiction.

8.5. The biological feature that allows lotus leaves to repel water is the specific microstructure on their surface that has tiny protuberances covered with waxy hydrophobic crystals. Additionally, this microstructure has a small contact area, which is needed to reduce friction in MEMS/NEMS.

8.7. This biological feature is easy to transfer to the surface of MEMS/NEMS parts because it is mostly of a geometrical feature (see Fig. 4).

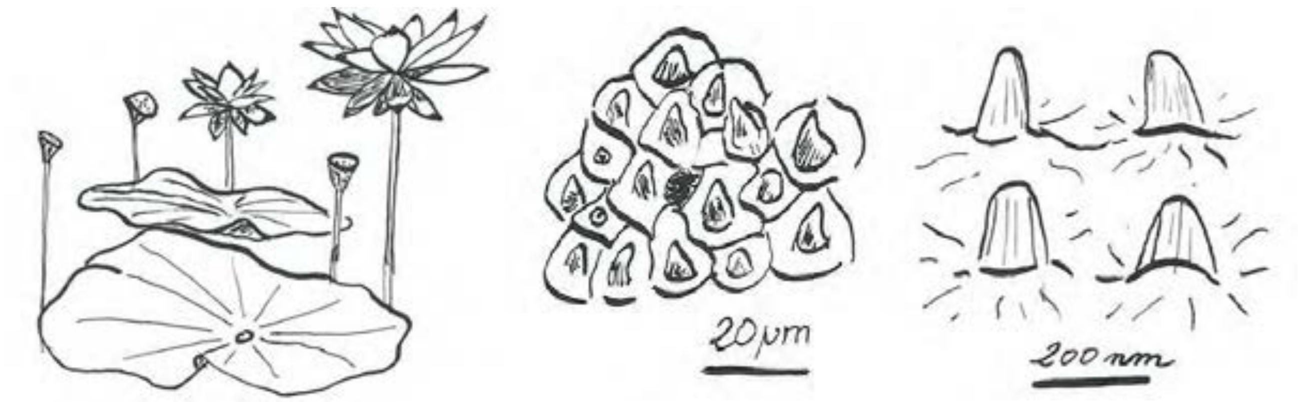

Fig. 4. Lotus leaves, microstructure of their surface and biomimetic nanopatterns suitable for use in MEMS/NEMS [28] [29]

This solution is described by Arvind Singh and Kahp-Yang Suh [29] and is claimed to be very efficient.

5.4. Test of the algorithm on another micro-level case study: wet adhesive

This case study relates to the development of wet adhesive. One possible application is the adhesion of small mosaic tiles in swimming pools and Turkish baths. Another potential application is the adhesion of structural parts of an aeronautical component in non-standard conditions, i.e. in oily or humid conditions. Usually the aforementioned mosaic tiles detach prematurely from their support due to the adhesive's poor durability, which is probably of a chemical and mechanical nature.

Since the MPV and key problem have already been identified, we will start with step 5 of the proposed algorithm.

5. Required parameters: long durability under water, the surface of the considered support is flat.

6. Generalized function that provides wet adhesion: to grasp a flat, solid surface.

7. Flat solids that are available "in high concentration" in Nature are bare mountains, and rocky lake, river or sea shores, and rocky surfaces in the ocean depths. For example, sea animals or plants that attach to rocks can be selected as leading areas, as well as animals that attach to other marine animals such as sharks and baleen whales.

8.1. This step suggests looking for natural non-biological objects that attach to flat rocks.

8.2. One may consider shellfish, whale barnacles, remora fish, encrusting marine algae, or sea anemone. For example, marine mussels adhere very well to hard surfaces despite the action of strong sea waves (often over 25 m/s) [30] and often contaminated by sand. To adhere to the solid surface, they use a byssus, which is a bundle of filaments whose extremities are tiny feet (plaques).

8.3. In this case study we do not express the key problem as a contradiction.

8.5. The global biological feature that allows for the adhesion of the mussel foot plaque on a flat surface is rather complex; intensive academic research has described it in detail as a specific spatial arrangement of seven different mussel foot proteins (mfps) of polyelectrolyte nature within the plaque (see Fig. 5). Indeed, mfp-3s, mfp-3f and mfp-5 are localized in the plaque-support interface [30].

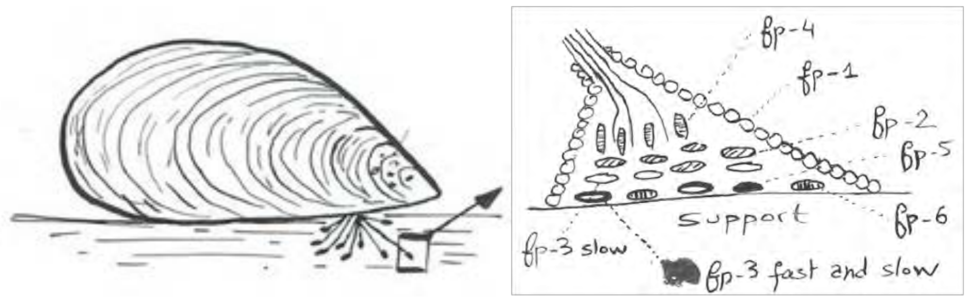

Fig. 5. Marine mussel attached by its byssus to a solid surface and schematic of the different types of mussel foot proteins and their respective locations in the mussel plaque [30]

8.6. Assuming the chemical structure of the three mfps at the place of contact is responsible for the wet adhesion of marine mussels, this biological feature seems as though it can be easily transformed into a chemical feature.

8.7. Unfortunately, transferring this chemical feature to the synthetic adhesive is not easy. First, the considered proteins have complex chemical structures and, therefore, cannot be easily synthetized. Second, there is a wide variety of proteins and their interactions are not well-known. Thus, some simplifications must be made. It turns out that Dopa (3,4-dihydroxyphenylalanine) is the main chemical responsible for the functionality of mfps. If the Dopa functionality is the only feature that is used in a synthetic adhesive, the wet adhesion fails because Dopa is very susceptible to oxidation. This simplification is clearly excessive. Actually, mussels have "solved" the Dopa oxidation problem at the micro-level. First, mussels use specific micro-environmental conditions of adhesive protein deposition which promote a complex coacervation

[30], i.e. a unique type of electrostatically-driven liquid-liquid phase separation. Second, they have the following chemical features that provide the targeted wet adhesion, which have been transferred with success onto copolyampholytes [31]:

• high proportion of non-polar, hydrophobic amino acid residues in the flanking sequence around Dopa;

• dynamic pH control, from acidic to neutral;

• ionic strength less than 100 mM;

• catechol functionality;

• amphiphilic functionality;

• ionic functionality.

This example illustrates how tedious and complex the transfer of biological features can be.

Finally, as for the mosaic tiles in Turkish baths, which require a high temperature wet adhesion, a similar approach could be carried out. This may necessitate a study of the biological features involved in the wet adhesion of some animals living at high temperatures (up to 60°C) on hydrothermal vents in the deep ocean, namely "black smokers" and "white smokers".

5.5. Test of the algorithm on another micro-level case study: bacterial cement

The problem considered in this case study relates to reducing power/heat consumption during the production of concrete and bricks that are used in the building construction industry. Cement production is one of the most power-consuming industries: it alone is responsible for about 5% of the global carbon dioxide emissions. High levels of CO_2 are emitted when raw materials are converted into Portland cement, and when bricks are hardened using the traditional method, because in both cases high-heat processes are involved.

Therefore, in order to reduce power/heat consumption in these areas it is necessary to develop processes for cement production that do not require heat at all.

Since the MPV and key problem are already identified, we will start with step 5 of the proposed algorithm.

5. Required parameters of the process: low heat consumption, i.e. low temperature.

6. Generalized function that we need to perform at low temperature: (1) to produce solid substance out of fluid; or (2) to hold solid particles together using fluid.

7. Fluids that are available "in high concentration" in Nature are water, saltwater, blood or other fluids in animal bodies, plants, or biological cells. For example, aquatic organisms (plants, animals, bacteria, etc.) can be selected as leading areas.

8.1. This step suggests looking for natural non-biological solid objects that were created out of fluids. One example is stalactites and stalagmites that appear in caves.

8.2. We could look at, for example, a termite mound, corals that create solid reefs, or mollusks that create their hard shells out of sea water. The formation of various stones in the human body can also be considered. Another promising area to look at is bacteria that make calcium precipitate, thus forming 'bacterial cement' [32].

8.3. In this case study we do not express the key problem as a contradiction.

8.5. The biological feature that allows calcium precipitating bacteria to form cement out of fluid is their ability to conduct/promote multiple chemical reactions that result in calcium precipitation under normal conditions.

8.6. This biological feature is easy to use if you find or breed bacteria that produce cement fast enough.

Such a solution has been developed and commercialized by bioMASON Inc. [33], who has already built a pilot plant where bricks are “grown” using special bacteria.

6. Conclusions

A specific algorithm named FOS in Nature has been proposed here. This algorithm is based on the eleven steps of FOS, a well-known, powerful solving tool in modern TRIZ. FOS in Nature differs from the original FOS in that it augments steps 7 and 8, so as to help identify the function-leading areas in Nature and natural solutions that can be found therein. It should be noted that the function-leading areas are non-biological phenomena or biocomponents found in natural environments linked to the object of the generalized function. The algorithm has been tested satisfactorily on five case-studies, two at macro-level and three at micro-level.

The present paper presents a work-in-progress. This research will continue in order to make the FOS in Nature more efficient. To do this, for example, a retrospective analysis of numerous biomimetic solutions should definitely help.

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ONLINE TRIZ TRAINING: EXPERIENCE WITH DEVELOPMENT AND DELIVERY

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Abstract

The paper presents an overview of distant online TRIZ training introduced by the author in 2012, and summarizes experience and results based on training of 314 students with different backgrounds who represent various customer segments: from university students to top managers of large industrial companies. The paper presents some statistical data related to the courses taken, geography of students, and students occupations. Finally, the advantages and disadvantages of online TRIZ training based on the author's experience are discussed.

Keywords: TRIZ training, online training, distant training.

1. Introduction

The first ever TRIZ course was delivered by the founder of TRIZ, G. Altshuller in 1958 [1] in Baku, Azerbaijan, a part of the USSR at that time. The distinctive feature of the TRIZ training courses which followed in the ex-USSR was a strong focus on presenting theoretical TRIZ foundations in high detail and explaining cases by a trainer or a group of trainers rather than on performing practical work by the participants in a classroom. TRIZ training courses used to take 120-160 hours of classroom time spent for lecturing excluding individual or group practice. The students used to perform practical exercises during homework which took 1-3 hours after each training day. Thus in total such courses resulted in about 200 hours of training.

The first attempts to transfer such a format to Western audience resulted in mixed positive and negative experiences, both within academy and industry. Major contradiction was created by the demand for balancing the time interval for lectures and presentations and the time interval for instructor-led practice on cases in a classroom which was not possible provided that neither universities nor companies within industry were willing to introduce 160-200 hours courses. In most cases, the demand was to fit a course program to 40-60 hours.

Modern professional education demands a person to learn and master skills with a training subject or a tool in as short a time as possible. It is why, in modern professional education and training, the ratio between theory and practice gradually moves towards practice, and nowadays it is approximately 20% to 80% to increase retention rate by students according to the "Learning

Pyramid" theory [2]. In academic education, one can observe the same trend: today approximately 60-70% of a course is given to practice while a considerable part of theoretical material a student has to learn outside a classroom.

The problems with traditional TRIZ training are discussed in [3]. From the practical side, modern TRIZ is well developed and provides a set of methods, tools and techniques, with about 30 TRIZ tools and techniques used more or less on a broad scale worldwide. One the other hand, TRIZ is a system of thinking, which is hard to master without understanding its theoretical basis which has strong fundamental background based on a scientific approach. Successful TRIZ competence can only emerge from combining decent knowledge of theoretical TRIZ foundations and well-developed skills of working with different TRIZ methods and techniques. But taking into account the abovementioned disbalance of learning time towards practice does not give an opportunity to learn theory to the level which would be necessary to use TRIZ tools as effectively as possible.

Such contradiction can be eliminated, for example, by separating conflicting demands in time: for example, a student can learn theory on his/her own, using books or video-lectures before the workshop, and only then come to a practical training. However, the experience shows that in such case sub-tasks emerge: more often than not students come to a workshop and say honestly that they did not have enough time to prepare for it. They say: "Let me practice now, and I will read about it later". Usually, it happens so at professional training. The problem is that by far not everyone actually reads after the training workshop. This contradiction must be eliminated.

2. Online Training Process

2.1. Basis for Online Training

Before engaging to online training activities in 2012, the author had considerable experience with delivering both public and in-house TRIZ training courses and workshops in industry and academia worldwide. By 2012, over 200 professional training courses and workshops in the traditional format were delivered by the author with an average time of 8-120 hours per course, and the courses took place in 28 countries. In 2007, a 80-hour TRIZ course (with extension to 132 hours) was introduced for B.Sc. and M.Sc. students at Twente University in the Netherlands [4]. These activities resulted in the refining the author's approach to TRIZ training and the availability of training materials including practical cases which could be used for organizing distant training online.

2.2. Online Training Format

There are a number of different formats of e-learning, among which two dominate: *on-demand training* which does not involve instructor and *instructor-led training*. Surveys show that today 58 percent of organizations prefer to use on-demand learning for compliance training, compared to 12 percent who prefer classroom instructor-led training [5]. With respect to TRIZ, fully instructor-independent on-demand training format can only be used for learning theoretical background of TRIZ. However learning TRIZ tools and techniques requires intensive assistance of instructor, preferably on the individual basis. Even if knowledge of the theory and the tools can be learned without instructor and evaluated by automated knowledge tests, mastering practical skills with inventive problem solving requires coaching and trainer's assistance, especially in the situations when training is based on solving actual, not educational problems which is the most effective way of learn the valid use of the TRIZ tools as confirmed by traditional training formats.

As a conclusion, online TRIZ training has to blend both approaches. A typical flowchart of the distant TRIZ training process is shown in Fig. 1. After subscribing to a course, a student receives a courseware set which includes videos of lectures, texts of assignments to perform, samples of previously solved cases, workbooks, reference materials.

To learn a specific subject, a student watches pre-recorded video materials of a training module, in which the trainer demonstrates slides with presentations, cases, images and other relevant information. The video materials are available for watching any time off-line.

After watching the video lectures on a certain module, a student prepares questions which will be answered by the trainer during interactive sessions (“e-sessions”). During e-sessions, the student can view the desktop of a PC of a trainer together with a webcam window of a trainer at the screens of their PCs. Voice communication is provided through audio chat. Students can also broadcast their own video from their webcams if they wish.

Assignments are performed by students in the offline mode between e-sessions. Each student has to perform s number of individual assignments to complete a course. Usually there are 7-12 assignments per specific course which correspond to training modules included to the course. Each completed assignment is made as a separate document and is sent to the trainer prior to the next e-session to enable enough time to the trainer to study the results of the assignment. E-sessions are used to evaluate the assignments and provide feedback to the student and last from 30 to 90 minutes.

There are two types of assignments: educational and real-life. In the educational assignments, all tasks including a problem to analyze or solve are defined by the trainer. However, it is highly preferred that a student performs a real-life assignment on the actual problem or a system related to his own professional area. To ensure confidentiality, the trainer signs non-disclosure documents if required.

If the student has a question arising while working offline, he can contact the trainer to request extra e-session. Extra communication time between the student and the trainer during the training course is not charged as long as it is necessary to reach the goals of training.

Date and time of each next e-session are flexible and are agreed depending on availability of the trainer and the student.

Total time for taking courses vary. On average, time to complete a course is from two weeks to two months for the courses of MATRIZ Level 1 and from 1 to 3 months for the courses of MATRIZ Level 2. Level 3 usually requires from 3 to 6 months. Since training is individual, time frames of taking the courses are defined by a student and a trainer.

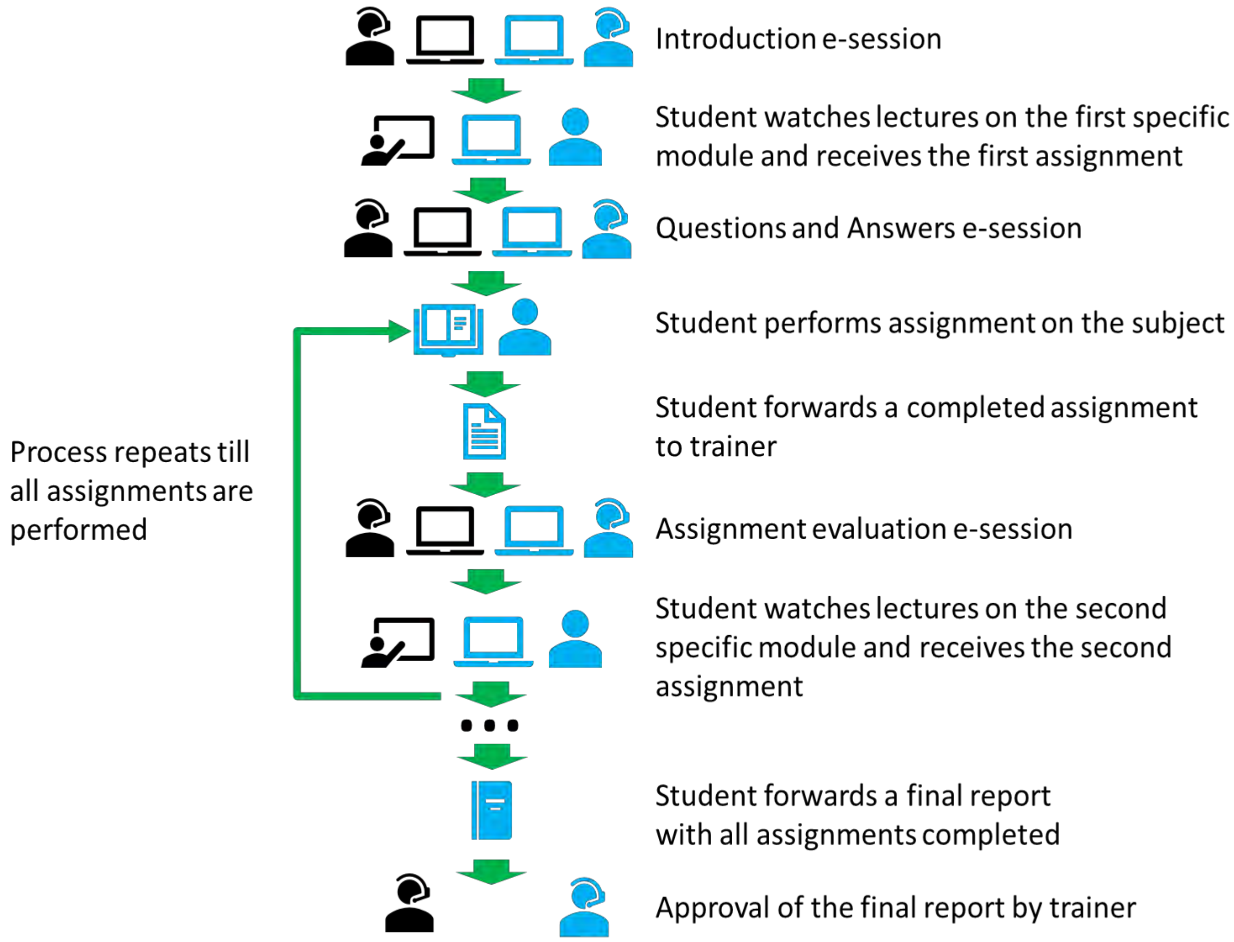

Fig. 1. Flowchart presenting distant TRIZ training process.

3. Results

3.1. Course Subjects

Since 2012, the following two categories of online courses have been offered [6]:

- MATRIZ Certification courses which meet certification demands established by MATRIZ (Levels 1-3) [7]. Successful completion of such courses is currently awarded by a MATRIZ certificate of a corresponding level. Granting MATRIZ certificates was introduced in 2014.
- Specific courses on separate subjects. These courses help students to better understand and practice with specific subjects, such as a System of Standard Inventive Solutions, or Function Analysis, or ARIZ, and so forth. Usually these courses are taken by those who already learned TRIZ from some other vendors or tried to learn TRIZ without engaging to training courses. Students who successfully complete such courses receive certificates of the TRIZ Training International Centre.

Fig. 2 shows how many courses in each category were acquired by May 1, 2017. As seen, most of the courses acquired were TRIZ for Technology and Engineering, Level 1 (126) and courses on specific subjects (90).

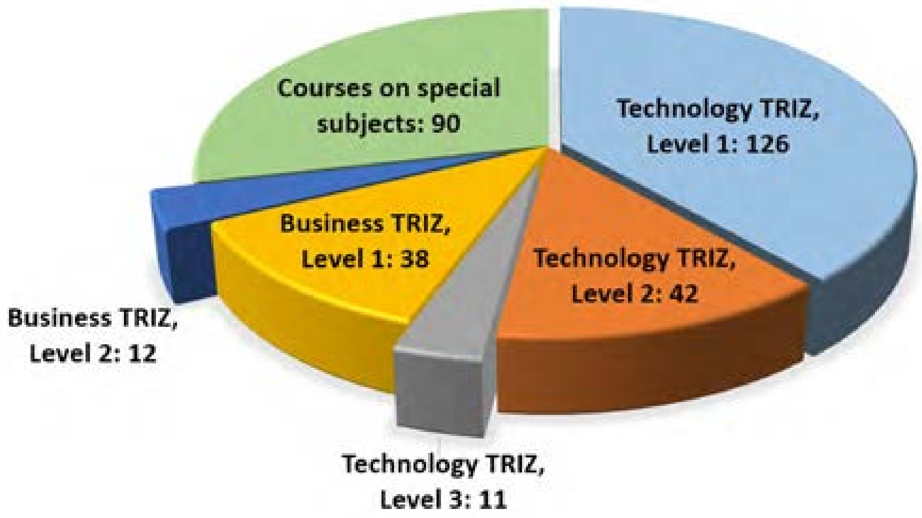

Fig. 2. Numbers of persons who took different courses delivered by distance learning at ICG T&C, 2012-2016 (Technology TRIZ Level 3 course was introduced in 2016). Levels 1-3 correspond to the classification by MATRIZ.

3.2. Customers Segmentation

The online TRIZ courses require students to possess some basic background in the field of business or engineering but it is enough for the first-grade university students or other individuals to engage. Fig. 3 shows current segmentation of the student occupations who took online courses in 2012 - 2016.

Fig. 3. Segmentation of online students occupations.

3.3. Training Geography

It is quite interesting that most of online students come from the Netherlands where the main offices of ICG Training & Consulting are located and from Germany which shares the border with the Netherlands. Provided that information on the online training is disseminated worldwide without focusing on any specific region and there is no difference for the online audience where to take the course since only availability of the Internet is needed, it can be explained by psychological factors where the most important is probably our psychological inertia. Figure 8 shows a chart with a number of students per country who participated in the online training in 2012-2016.

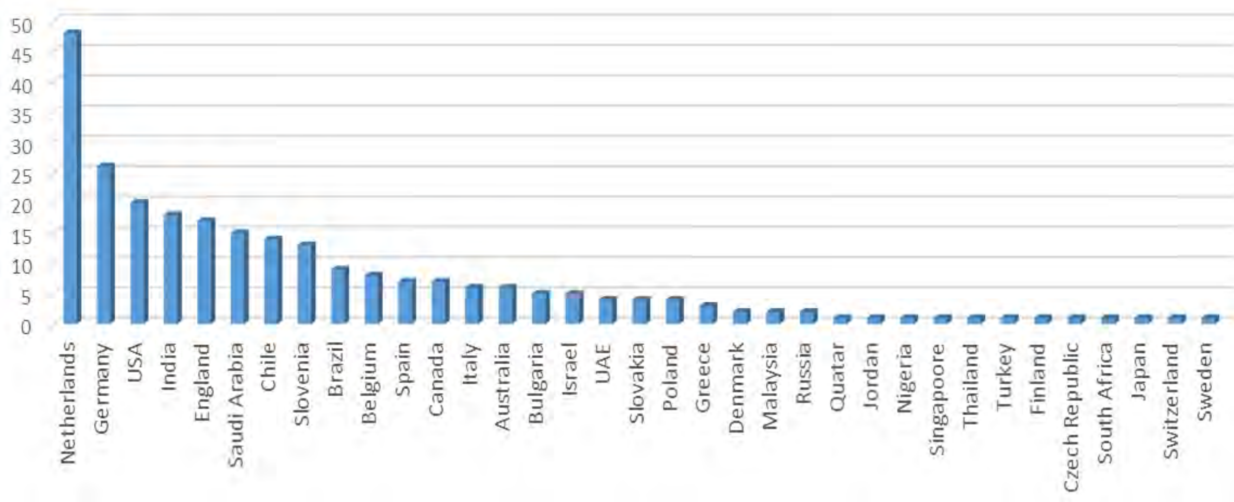

Fig. 8. Number of online students from different countries who took distance training from ICG T&C, 2012-2016

3.4. Tests and Evaluations

In addition to learning and understanding theoretical foundations, the primary goal of TRIZ training courses is, first of all, learning how to successfully apply TRIZ processes and TRIZ tools in practice. Which means that tests and evaluations of student's accomplishments must be done on the basis of assessment how well a student can apply TRIZ analysis, modeling and solving tools to deal with actual problems and challenges. As clear, to do it, knowledge tests only are not enough. There is only one way to evaluate the acquired knowledge and skills: to check how the student applies TRIZ on practical cases. Traditional training format of public or in-company courses does not leave much time neither to a student nor a trainer to thoroughly work with each tool and test the results due to time constraints. However, this problem is solved in the online distant training: each assignment performed and delivered by a student demonstrates his or her level of practical skills with a high degree of relevance.

For example, one of the students from UK who works in construction industry, solved 5 actual problems during online training. Each solution was a result on completing an assignment on certain module during taking the course on MATRIZ Level 3. All 5 solutions were implemented in his company and used in new patent applications before the course was completed. A similar result was shown by a student from Germany (automotive industry) who successfully solved three problems during his study of MATRIZ Level 2 course, and these solutions were approved patentable as well.

3.5. Students Retention

One of the main concerns which is often mentioned about online education is high attrition rate. It is estimated that totally, 40% to 80% online students drop out of online classes [8]. In our case, each student who delivered the final course assignment completed the course successfully. 42 students from total 314 have not completed their courses by their predefined deadline which means 13%, relatively low number compared with general statistics. Some of the students disappeared during the training process, but some of them returned after a while and continued training.

4. Advantages and Disadvantages of Online TRIZ Training

Based on the author's experience, the advantages of online distant TRIZ learning are as follows:

1. There is no time restrictions for a student to watch, listen and read all lecture and presentation materials as well as perform and deliver all practical assignments.
2. There is no time pressure to absorb the material by a student. It is well known that people have different rates of absorbing and processing information which creates a problem for some of them if the pace of training in a traditional classroom is fast. All the video lectures and other course materials are in full possession by a student so the video lectures or their parts can be watched several times if necessary.
3. Video lectures and presentations are edited before being included to the course materials. It helps to reduce time for watching and listening, and provides completeness of material since sometimes a trainer forgets or skips something in a real-life class.
4. The training materials are continuously updated by a trainer which provides an ability to supply new materials to a student during the course.
5. Quality and completeness of off-site assignments performed by students is considerably higher than during traditional classroom work due to the lack of time constraints. A recent presentation of one of the students from India who completed MATRIZ Level 3 program included 339 illustrated and well-structured slides.
6. Individual approach and coaching during e-sessions help a student to better achieve his/her training goals.
7. A student can safely work on his own cases or cases of his organizations to perform assignments due to confidentiality and non-disclosure agreements signed by a trainer. It often results in generating new patentable solution ideas during the courses.
8. Both student and trainer can flexibly manage their e-sessions which are conducted at dates and times convenient for both.
9. Online training provides considerable reduction of costs, specifically for a student since there is no need to travel and stay at the course location.

At the same time, there are certain disadvantages compared to traditional class-room training:

1. Lack of social interaction with other students. Such interaction is important to deeper understand the material learned, and, specifically, certain small details which can be critical. Such interaction occurs during breaks, discussions of presentation, outdoor meetings, and, most importantly, during working on actual cases in groups.
2. Time flexibility creates a contradiction: for well self-disciplined students it works fine, but less self-disciplined students tend to considerably extend the duration of taking a course which leads to forgetting previously learned material. Introducing harsh time limits does not help much because it creates unneeded pressure and eliminates the advantage of time flexibility.
3. Increased time of a trainer per student. Comparing to traditional classroom training, it is increased at least, twice which rises the trainer's workload and reduces his capacity.

4. Conclusions

As the summary of experience with online TRIZ training shown above demonstrates, the key advantages of the online training format compared to classical classroom training are flexible time management, more time spent by a trainer for individual assistance and coaching of each student during training, and a higher quality of assignments delivered by the students.

Another key advantage is a possibility of a student to safely work on real life actual problems during the courses.

However, the costs of online training still remain a bit too high for certain customer segments, specifically for college and university students. It is explained by the necessity of dedicating trainer's time for an individual approach to assist and coach students.

Another challenge is how to reinforce training with social interaction. It can be done by introducing a blended mode of training which is a sort of a bi-system combining both distant and classroom training. Such solution could allow students to travel to a course location only for a short period of time provided the student took a considerable part of the course online and to get experience with working on practical cases with other students.

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OPEN INNOVATION: TRIZ APPROACH VS. CROWDSOURCING

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Abstract

The logic behind Open Innovation is compelling, but implementation can be difficult. In many cases, Open Innovation has failed to live up to its full potential. In our perspective, the problem lies not in the concept of looking externally for help, but in its execution. Unfortunately, the term "Open Innovation" in many cases, has become synonymous with Crowdsourcing. Crowdsourcing is a system, which relies on the probability that the right technology exists and the right person will respond to the challenge. It ensures neither the right problems being addressed, nor does it filter out the bad ideas.

TRIZ provides a practical means for realizing the benefits of Open Innovation. Several cornerstones of TRIZ disciplined process of Open Innovation distinguish it from the Crowd Sourcing.

First, before searching for solutions, the underlying problems behind the challenge should first be understood. Open Innovation should focus on these key problems, instead of the initial ones.

Second, focus the external search on functions, instead of specific design components or technologies.

Third, search for solutions in functionally similar industries and areas of science and engineering where companies have already invested in R&D to develop the best possible solutions.

Fourth, focus on adapting the solutions to the application at hand, rather than inventing a solution from scratch.

Keywords: at least three keywords that reflect the theme of work.

1. The Quest of Revenue Growth Acceleration

Top line (revenue) and bottom line (net profits) growth are basic business imperatives. Today's multinational corporations, however, are asked to deliver much more than their predecessors, in a much tougher global business climate. Consider the S&P 500 revenues (dollars per share) and business sales (trillion $) over the past two decades for a moment. Their steep ascend reflects the intense pressures on businesses to maintain revenue growth. It also demonstrates, of course, their ability to continue doing so [1].

"… Intellectual assets taken as a whole are rapidly becoming the key to value creation"

Fig. 1. S&P 500 Revenues

Yet, CEO confidence that revenues will always continue to grow as the graph seems to suggest is distinctly low – lower than one would expect listening to the CEOs' quarterly report chats with investors and the press. PricewaterhouseCoopers International surveyed 1,258 CEOs in 60 countries and no less than 48% expected a decline in revenues, 34% anticipated stagnation, and no more than 15% assumed revenues to increase [2].

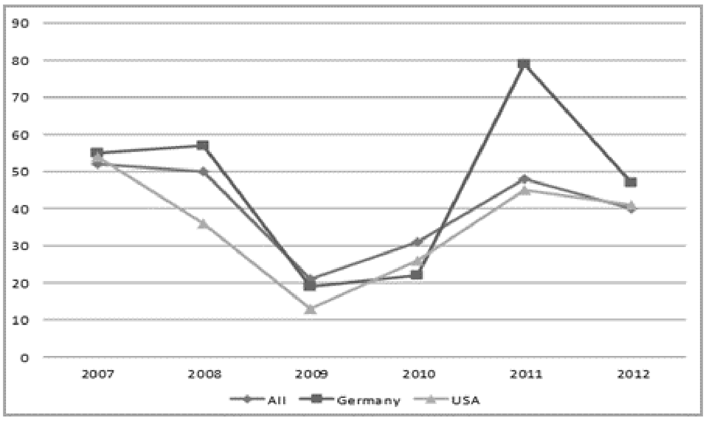

Fig. 2. CEO Confidence for Revenue Growth

Moreover, for many CEOs revenue growth alone is not sufficient. In a survey of 200 executives by Hackett Group (2012), 98% of CEOs stated that "accelerating revenue growth" – not just growing revenue but also accelerating the growth – was their top priority. By all accounts, they are fighting a tough battle as revenue growth figures have been showing continuing moderation [3].

2. The Key to Value Creation

Some economists regard revenue growth moderation as inevitable, a result of the natural limits of selling ever more products into relatively unchanged markets [4]. Others, however, argue that the markets' fluidity and constantly changing consumer needs create a highly dynamic environment in which *transformational innovation* (more on this later) combined with the right business strategies can, indeed, achieve an increase in revenue growth rates.

"CEO confidence that revenues will continue to grow is distinctly low"

The OECD sees innovation as imperative for revenue growth. In an OECD report on innovation and growth, the authors stated "… intellectual assets taken as a whole — … human capital, R&D and capacity to conduct it, patent valuations as well as intangible assets such as brand value or firm-specific knowledge — are rapidly becoming the key to value creation." [5]

The Institute for Prospective Technological Studies concludes in "Profits, R&D and Innovation: A Model and a Test" that "the growth of industries' profits is jointly driven by the 'pull' effect of expanding demand and value added, and by the 'push' effect of *the success of innovation performance*." The authors further argue that this "pull" and "push" is supported by the parallel efforts of searching for technological competitiveness — through R&D — and for cost competitiveness — through the adoption of new technologies." [6]

Most CEOs agree that increasing the success rate of innovation is a key means to driving growth. Automotive power train manufacturer BorgWarner, for example, was seeing declining cash flow when the U.S. economy deteriorated in 2009. The firm reduced wages, closed a plant, and laid off 5,000 employees. However, they did not cut R&D. "Innovation and new technology don't happen overnight, so you have to fund them," CEO Timothy Manganello told NYSE Magazine. "Spending money on R&D was the easiest decision I made all year." In a survey, 40 percent of CEOs said they were increasing spending on research and development [7].

The "success of innovation performance" is a critical term here, but innovation success can be very difficult to measure – "demonstrating ROI" has been cited repeatedly as a key challenge across all industries [8]. Most innovation experts would agree, however, that ROI will typically be small because of an optimization effort and greater from more transformational innovation, reason why the latter is increasingly seen as an important strategic direction to achieve revenue growth acceleration.

3. The Difficulty with Different Knowledge

There are various terms that partially or entirely overlap when it comes to transformational innovation, some with precise definitions, and others less so. For example*, Disruptive Innovation, Destructive Innovation, Radical Innovation*, and *Breakthrough Innovation*. This paper prefers the term *Disruptive Innovation*, albeit with a different definition than Clayton Christensen's. We define Disruptive Innovation, as innovation that addresses a major unfulfilled user need and/or that "jumps" from one scientific action principle to the next (for example, from mechanical calculator to electronic digital computer).

Disruptive Innovation is rarely achieved with internal subject matter expertise alone – it often requires an interdisciplinary approach and depends therefore on identifying, accessing, adopting, and adapting *external knowledge*, another major challenge that many firms say they struggle with [9].

Ian Brinkley of The Work Foundation, a Lancaster university-based expert group on work and its future, argued in a presentation that: "Across all sectors, innovation depends critically on the ability of firms and organizations … to exploit the constant flow of ideas, innovations and technologies through global networks."

"Despite – or, because of – the massive worldwide R&D expenditure ($1.4 trillion in 2012), identifying the right slice of knowledge is increasingly difficult."

These networks should include all stakeholders … customers, suppliers, and even competitors [10].

It is a commonly heard theme, often repeated at conferences, in white papers, and in the press. In many ways, awareness of the "knowledge" requirement — be it internal or external — for success has been rising dramatically. Since the mid-1990s, investment in "knowledge" has grown more rapidly than investment in machinery and equipment and it has even surpassed the latter in the United States [11].

Yet, despite – or, as some argue, *because of* – the massive worldwide R&D expenditure (R&D efforts grew to $1.4 trillion in 2012) [12] and the resulting knowledge explosion, identifying the right slice of knowledge for a specific problem has become increasingly difficult. As one innovation thinker put it: "How do we deal with knowledge in a world *filled* with knowledge?" By the way, the word "knowledge" is too general. It covers scientific expertise, information about products, technologies, institutions, etc. The problem of a right knowledge identification is even more challenging because of different types of knowledge sources – publications, patents, databases, registers, websites, experts' brains, etc.

Harvard energy policy expert Matthew Bunn noted that knowledge growth makes innovation more difficult: "… it is true that as particular areas of science and technology become more complex and the "easy" discoveries get made, it becomes more difficult and requires more resources to push their frontiers further," he writes [13]. Author Kevin Kelly goes even further. He makes a convincing point that as knowledge is growing exponentially, so is our ignorance. "The paradox of science is that every answer breeds at least two new questions. More answers, more questions. Telescopes and microscopes expanded not only what we knew, but also what we did not know. They allowed us to spy into our ignorance. New and better tools permit us new and better questions. All our knowledge about subatomic particles derived from the new questions generated after we invented an atom smasher." [14]

4. The Limited Interpretation of "Open Innovation"

To navigate this knowledge explosion, innovators are confronted with having to find effective and efficient ways to bridge the gaps between their expertise and other fields of expertise. In practical terms, this means that they have to somehow request *(formulate the right problem), identify, adopt, adapt, and integrate unfamiliar knowledge* from unfamiliar areas of science and technology.

This identification process is a generally overlooked aspect of Open Innovation and a key reason why Open Innovation, since Henry William Chesbrough coined it, has been less successful than initially anticipated. Just take, for example, the impressive 179-page report titled "Understanding Knowledge Societies" published by The Department of Economic and Social Affairs of the United Nations Secretariat [15], which extensively investigates modern knowledge creation and its role in society. In it, no mention is made of methods for finding a specific piece of knowledge in the swelling ocean of global knowledge.

This lack of methods to identify precise pieces of external knowledge has contributed to limited applications of Open Innovation, as most firms prefer to stay well within their knowledge domain while sourcing knowledge outside the firm. For sure, day-to-day Open Innovation attempts are evident across most industries; rarely, however, do they extend significantly beyond an industry's "comfort zone." The Life Sciences, for example, are witnessing a convergence of public and private R&D toward open innovation and open source information. Recently, GlaxoSmithKline, Novartis, Pfizer, and Eli Lilly joined the Structural Genomics Consortium, a public-private partnership aimed at the discovery of new medicines through open access research [16]. These pharmaceutical firms, of course, share or are intimately familiar with each other's' core competencies.

On the manufacturing side, an impressive 81% of U.S. companies said in the same survey that they are involved with some type of collaborative R&D. Not much of this collaboration crosses industry lines, though. A recent study based on 8,180 observations shows that the importance of internal sources for inventions is three times higher than that of external sources. It also indicates that the stakeholders in a firm's value chain, from suppliers to end users, serve as the most frequent sources of knowledge [17].

Enkel and Gassmann of the Swiss Institute of Technology Management lament in R&D Management (2010): "… innovation studies do not recognize the value of partners outside the value chain …. Drivers of innovation, such as technology fusion, shorter innovation cycles, the mobility of workers across industries, and the global availability of knowledge, make accessing external technologies imperative as well as easier." They conclude that: "The first studies on the optimal cognitive distance between alliance partners find that in industry or field of experience, distance is not counterproductive but can be a source of both *disruptive and incremental innovation* [18].

In the academic world, interdisciplinary translation and synthesis is increasingly deemed critical, as issues around a complex research effort require full involvement by more and more disciplines. "… this is not a deviant exception, but a common path for the modern academic. We need to learn how to understand, navigate and employ multiple and often contrary ways of knowing," writes Clinton Golding of the Centre for the Study of Higher Education [19].

5. A Tower of Babel?

While learning to navigate the ways of knowing sounds like a logical approach, the reality of hundreds of increasingly complex yet completely disconnected disciplines is stark. Basarab Nicolescu, the president and founder of the International Center for Transdisciplinary Research and Studies, asks darkly: "Is a modern tower of Babel inevitable?" He sees no simple solutions for one discipline relating effectively to another: "How can a theoretical particle physicist truly dialogue with a neurophysiologist, … a biologist with an economist beyond mouthing more or less trivial generalities? … Disciplinary language is an apparently insurmountable barrier for a neophyte, and each of us is a neophyte in some area." [20].

> "Cognitive distance between partners is not counterproductive but can be a source of disruptive and incremental innovation."

Nicolescu goes even further, arguing that if we are all ignorant of each other's' disciplines, then any attempt to find common ground would merely result in one generalized incompetence, "for the simple reason that the sum total of competencies is not competence: on the technical level, the intersection between different domains of knowledge is an empty ensemble." To solve this "dangerous" condition, as he sees it, Nicolescu goes on to dive into Interdisciplinarity, Multidisciplinarity, and Transdisciplinarity, none of which is very pragmatic tools for knowledge translation.

One interesting attempt at overcoming Nicolescu's Tower of Babel is *cybernetics*, which proposes a formal language (with concepts and terminology) to build bridges between different disciplines based on the fact that many disciplines construct similar models, even if intended for different applications. A well-known example of such a model is control by negative feedback, which is used across many areas of science and engineering. By identifying these shared concepts, cybernetics serves as a kind of translator between them. [21]

6. An Emerging Lingua Franca

We will take a closer look at another approach, one that goes a step further than cybernetics in that it strips the domain context of a product or process down to its bare functions; so bare that they exist in many domains. The approach allows an R&D team that is looking to find a new way to perform a certain function to "cut through" the unknown domain-specific substance of unfamiliar technologies and identify the way they perform the needed function. Called *Function-Oriented Search* and developed by one of the authors Dr. Simon S. Litvin, the method comes very close to representing a *lingua franca* for the multitude of science and technology fields.

How does this work? Systems can perform on each other hundreds of typical functions. For example, DIRECT, MOVE, STOP, HEAT, PRESS, INFORM, or HOLD. They are typically identified via a technique called Function Analysis, the results of which are charted in a Functional Diagram. The Functional Diagram shows all the components of a "system" (the product or process) and the functions they perform on each other.

To illustrate this, below are three greatly simplified Functional Diagrams for three completely different systems in three different knowledge domains. For example, the left diagram might be for a tooth brush, the middle for a jet engine, and the one on the right might represent a banana. Despite the fact that these are distinctly different systems, all three have two components that perform the same function on each other — HOLD — albeit in different ways.

The purpose of Function-Oriented Search is to find other systems that perform the same function and then decide whether they perform this function more effectively and/or efficiently. If so, a R&D team may be able, for example, to dramatically innovate the jet engine by adopting and adapting the banana's way to perform the function HOLD.

Two components in three different products/processes within three completely different knowledge domains perform the same function albeit differently, using domain-specific technology (Fig. 3).

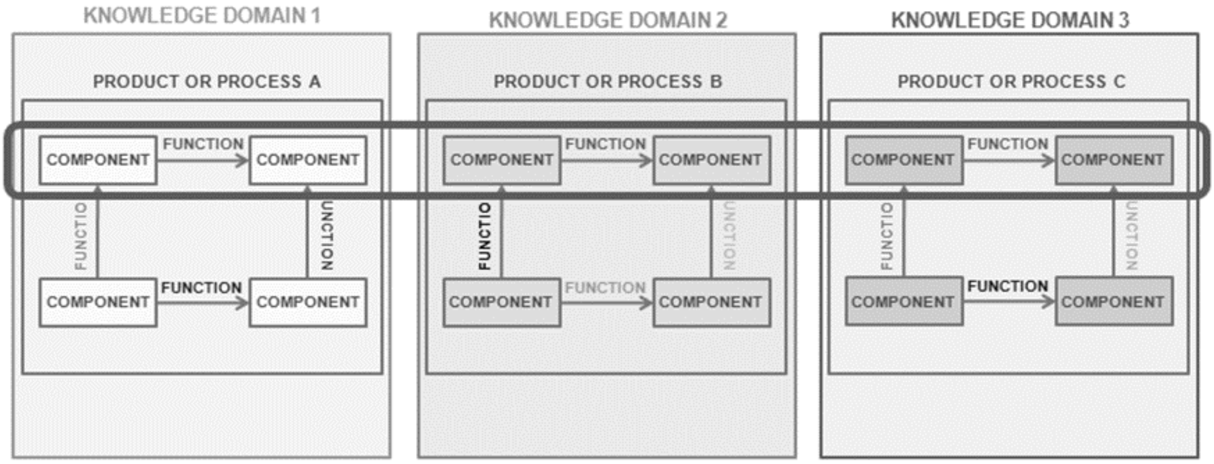

Fig. 3. Functions in Different Knowledge Domains

The technology with which the function is being performed in Knowledge Domain 3 could dramatically improve the product or process in Knowledge Domain 1. Since the function is the same for all domains, it can be found and the technology can then be adopted.

7. The 11th Flattener

An interesting parallel can be drawn with Thomas Friedman's *flatteners* in his best-selling book *The World Is Flat: A Brief History of the Twenty-First Century* (Picador, 2007) which analyzes globalization. As the title suggests, Friedman believes that geo-political boundaries no longer serve as barriers and that the world has flattened into a level playing field for all businesses regardless of where they are based. Cultural, legal, and lingual difficulties have been or can be overcome, he argues.

The ten things that *flattened* the world, according to Friedman, include: the collapse of the Berlin Wall; the introduction of Netscape; Outsourcing; Supply-chaining; Uploading; Wireless, Voice over Internet, and file sharing; etc. [22]

It appears that in many of Friedman's flatteners, *standards* and *protocols* have played a critical role, and as such, functions might be considered the 11th flattener. They represent a common language that breaks down the barriers between knowledge silos, levels global knowledge, and makes slices of unfamiliar knowledge identifiable without the need to master an entire body of knowledge. One might say that *the world is functionally flat*. It is interesting that Friedman is talking about geographical globalization. Effective functionally similar solution could be located in the same country, same city, and even the same company, but in a distant area of science and technology.

We strongly believe that Functional language is becoming the lingua franca of knowledge translation — a universal language that is effective, efficient, predictable and repeatable as a translator of knowledge from remote areas of science and practice to wherever such knowledge is needed.

Innovation providing companies like GEN3 Partners in the past and currently GEN TRIZ successfully apply Function-Oriented Search as a core tool in its overall innovation methodology. They have experienced first-hand how Function-Oriented Search often leads to the introduction of a new and more effective action principle for the product or process that's being innovated, which — as was argued above — is one of the main factors in successful Disruptive Innovation. An additional advantage is that less effort and resources are required to prove the effectiveness of the new solution as the technology already exists and is even routinely applied in a field where its effectiveness is critical [23].

Function Analysis is a cornerstone of a larger innovation approach, called GEN TRIZ Disciplined Innovation. GEN TRIZ Disciplined Innovation is a scientific approach to innovation execution that uses analytical tools to identify root causes of an innovation challenge and then finds functionally related practical solutions that can be adapted quickly, effectively, and with less risk.

We are commonly saying in our speeches at industry and innovation conferences: “Don’t always invent!” Our advice to R&D teams regardless of their industry is to do the analysis that allows them to reformulate problem statements into a language that is understood by the entire knowledge universe. That language is *functional* language [24, 25].

Example 1: “To stop solid particles”

When finding solutions for an effective anti-allergenic nasal filter for trapping small particles, looking at other nasal filters would be a direct analogy, with little chance of a breakthrough solution. Function-Oriented Search (FOS) represents an indirect analogy based on the same or similar functions. In the nasal filter, the function is “to stop solid particles.” FOS asks in which leading areas of industry stopping solid particles is absolutely critical. In this case, the cement industry would be relevant, as it cannot allow solid particles to be released in the air. The next question is: how does the cement industry perform this function? They use a vortex action principle (industrial centrifuge). Based on this finding a nasal filter with a vortex interior was developed (Fig. 4).

Fig. 4. Vortex

Example 2: “To remove a gas from a liquid”

A major computer chips manufacturer had significant problems with a photo resist polymer that bubbled when applied to a wafer — losses amounted to $1M/day (Fig. 5).

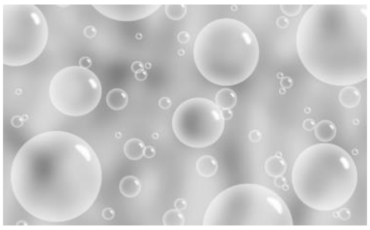

Fig. 5. Bubbles

> "Functions represent a common language that breaks down the barriers and makes slices of unfamiliar knowledge identifiable."

The company first looked at every possible cause using a common "manufacturing language," meaning that its engineers attempted to translate knowledge gained from solving problems in similar processes toward the issue. This approach did not identify the source of the problem.

Next, the firm tried to "translate" the knowledge of the best polymer scientists into new practice. This translation might have led to success, but was not practical since the polymer scientists required 2 years of research time and an investment of $3M.

In its third approach, the firm applied Function Analysis and Function-Oriented Search, translating the problem from the object-based language (photoresist chemistry, polymer science) to a function-based language. The former yielded a highly generalized problem statement: "How to control a gas in a liquid." The latter leveraged this domain-neutral statement to identify multiple technology areas where management of gas in a liquid is critical, including: carbonated beverage filling equipment, blood transfusion equipment, scuba diving gear, and Champagne production.

A simple solution was quickly found in Champagne production. The way the champagne industry manages gas levels in Champagne is with special valves in the pipes that carry the liquid. An adaptation of these champagne valves removed the bubbles from the photoresist polymer and resolved the issue.

8. Conclusions

In general, Open Innovation is a very promising concept compelling, but its implementation is challenging. The term "Open Innovation" in many cases, has become synonymous with Crowdsourcing. Crowdsourcing relies on the fact that the right technology exists somewhere, and the right person will respond to the challenge, which in many cases is not correct.

TRIZ provides exact practical tools for realizing the benefits of Open Innovation, making it an applied science. Several cornerstones of TRIZ Disciplined Open Innovation distinguish it from the Crowdsourcing.

First, before searching for solutions, Open Innovation should focus on key problems, instead of the initial ones.

Second, focus the external search on functions, instead of specific design components or technologies.

Third, search for solutions in functionally similar leading industries and areas of science and engineering where companies have already invested in R&D to develop the best possible solutions.

Fourth, focus on adapting the solutions to the application at hand, rather than inventing a solution from scratch.

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OPEN TRIZ SECOND WAVE TRIZ&TOC TOOL

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Abstract

I.- SUMMARY

The objective of this work is to present an assertive and systematic innovation management tool to promote innovative solutions in all areas of human development based on knowledge and technologies that are available in the world called OPEN TRIZ SECOND WAVE: TRIZ & TOC TOOL.

A new paradigm related to the Management of Systematic Operational Innovation is postulated, which is based on four pillars: Business Process Management, Lean Production and Six Sigma, Theory of Restrictions and TRIZ Inventive Problem Solving Theory.

To solve inventive problems, the "RCA + EC" diagram is introduced, which allows to formulate a multivariable problem and identify a set of contradictions to be solved.

"AATRIZ" is also introduced, which is an abductive algorithm that approximates the TRIZ solution to be applied, using only the contradiction matrix to solve a problem with multiple contradictions.

Finally, we examine the results of an actual implementation of the model.

II.- NEW PARADIGM

The new paradigm for innovation focuses on eliminating losses rather than cost reduction, understanding that as we approach the optimal business, costs are the result of probable hidden losses due to restrictions, limitations, risks, etc., that have not been resolved within our business.

The challenge of the new paradigm for innovation is to facilitate and make possible what seems impossible.

III.- "RCA + EC" DIAGRAM

The "RCA + EC" diagram is based on a joint application of two management tools: RCA +: Root Conflict Analysis & EC: Evaporating Cloud (Theory of Restrictions).

In the "RCA + EC" diagram it is necessary to declare a useful function and the positive and negative effects caused by the evaluated common object, according to the logical design with which the TOC evaporation cloud is constructed.

Using the "RCA + EC" diagram, all negative and positive effects must be checked and the TRIZ engineering parameters, that can be associated, should be found. It is possible that some effects can only be transitive relationships between the effects assigned to the TRIZ parameters.

We can identify all relevant contradictions that affect the useful function for the common object that we have declared.

IV. "AATRIZ", ALGORITHM APPROACH TO TRIZ SOLUTION

AATRIZ allows an accelerated and assertive identification of the main contradictions, which solves in great measure, the studied problem. Under an abductive analysis, we postulate hypotheses to find the main contradictions that contribute the maximum benefit with minimum changes, applying a mathematical algorithm that weighs the inventive principles of each pair of identified TRIZ engineering parameters, based on the number of repetitions in the contradiction table and according to their relative position in each specific contradiction (it was defined as a practical rule to evaluate up to 5 TRIZ engineering parameters).

V. APPLICATIONS OF THE MODEL

A) EFFICIENT ROBOTIZED STRIPPING MACHINE Affected by sheet adhesion

B) MAXIMIZING THE TRANSPORT BUSINESS BY FERRY Affected by the risk of capsizing by entering water into the cargo space

C) PERSONAL SAFETY AT WORK: Affected by the pressure of business results.

D) CONTINUOUS ELECTRIC GENERATION WITH FIXED MASS Affected by gravity.

Key words: TRIZ, TOC, TRIZ & TOC, Systematic Operational Innovation, "RCA + EC", "AATRIZ".

1. New Paradigm for Innovation

With a new approach, it is possible to understand when innovation begins to be applied in a business. This approach is best appreciated when comparing Maslow's pyramid with the commonly used models in business management and how they relate to TRIZ's inventive problem-solving theory, giving shape to what has been called the Innovare pyramid. See Fig. 1.

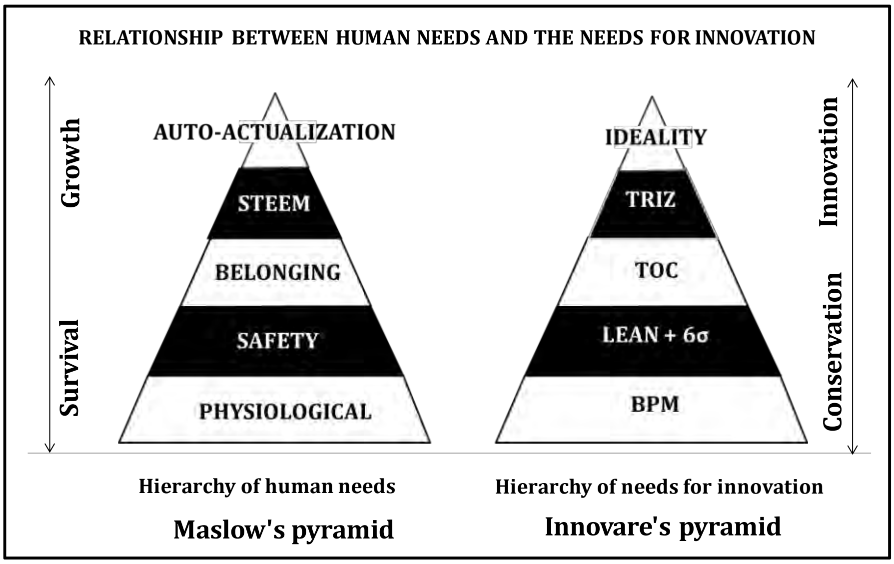


Fig. 1 Relationship between human needs and innovation needs

2. The Virtuous Circle of Business Management

The new paradigm for innovation allows us to see a virtuous cycle of business management, starting from the basic stage of business preservation to the maximum development stage, determined by the business innovation capabilities. See Fig. 2.

The new paradigm for innovation also focuses on the elimination of losses rather than cost reduction, understanding that as we approach the optimal business, costs are only the result of the probable hidden losses that exist due to restrictions, limitations, risks, etc., that have not been resolved within our business.

We understand as hidden losses, all costs incurred or income lost by the commitments assumed in our business, which correspond to certain conditions of our business that we declare impossible to change.

The challenge of the new paradigm for innovation is to facilitate and make possible what seems impossible.

Business process management provides the basic conditions for the existence of the company and production lean + six sigma orients the actions necessary to provide security to the business. Both management tools operate in a known loss environment, which, as Taguchi has postulated, are proportional to the square of the process variation.

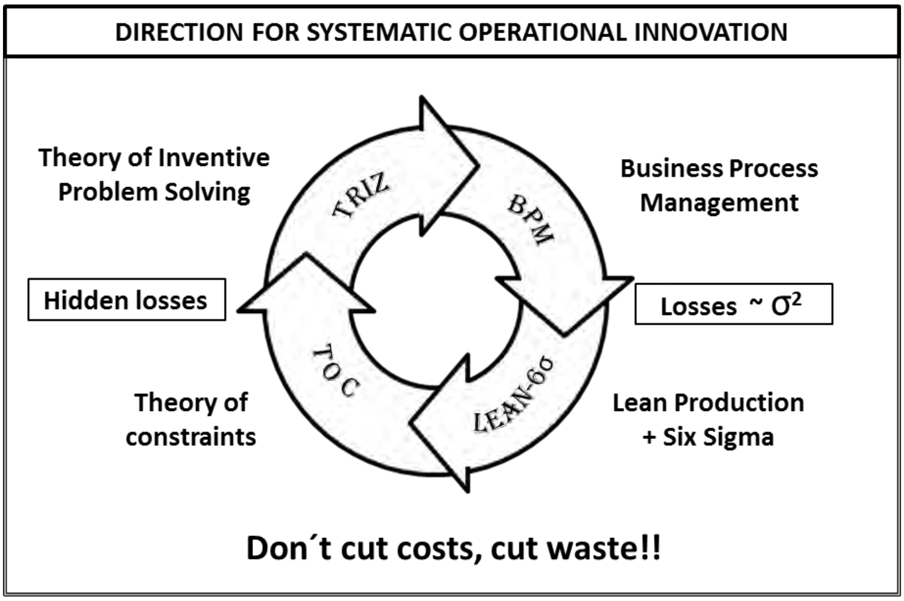


Fig. 2 Management in systematic operational innovation.

The restriction theory allows us to manage our constraints, the source of hidden losses, and analysis tools help us to guide the formulation of the contradiction to be solved by applying the theory of inventive problem-solving TRIZ.

This work is finally oriented to the formulation of multi-variable problems to solve the existing contradictions and with them the hidden losses.

3. GENERAL PRESENTATION "TRIZ & TOC" TOOL

According to neuroscience, who moves innovates and must be faster to win; then, it is necessary to innovate in a systematic way to accelerate change.

The novelty of this work is the development and practical application of an innovation tool called Open TRIZ Second Wave: TRIZ & TOC, which systematically integrates various existing methodologies for a fast and assertive resolution of multi-variable inventive problems by applying the following steps:

A. Definition of the objective function of the problem to be solved, corresponding to the desired result.

B. Determination of the objects that participate in the TRIZ model of substance-field of the problem to be solved. A problem can have a complex tree of substance-field relations and according to morphological analysis each substance-field relationship can be analyzed independently and each of them can offer a solution. Select the objects that relate to the specific problem to be solved.

C. Selection of the object to be evaluated, deduced from the defined substance-field model. This phase is critical, the engineering parameters and TRIZ inventive principles that apply to the problem must always be expressed in relation to the selected object.

D. Formulation of the problem in the "RCA + EC" diagram, based on the TOC Evaporation Cloud methodology, adapted to TRIZ, and in the RCA + methodology. For the formulation of the problem a physical or characteristic variable is determined that plays a fundamental role. Depending on the state or condition of this variable, negative and positive impacts on the objective function are determined. One state or condition must be real and the other could be real or "impossible" according to the existing paradigm. The states or conditions can be equal/same if they are real. Impacts are expressed in terms of the social and human context in which they occur to solve the problem.

E. Identification of the TRIZ engineering parameters associated with the problem, this determined by the identified negative and positive impacts.

F. Determination of the specific problem contradiction matrix, which includes all engineering parameters identified in the formulation of the problem. If the problem has been well formulated, the specific matrix contains the solution to the problem raised. The next step requires practical skills for an orderly and quick identification of the recommended solution.

G. Application of the abductive algorithm "AATRIZ" for the mathematical prioritization of the contradictions present in the matrix of contradictions of the problem:

I. The algorithm determines a prioritized order of weights of the inventive principles analyzed (WIP).

II. The algorithm determines a prioritized order of weights of the contradictions of the specific matrix of the problem (WSC).

The developed algorithm is fundamentally based on an expert intuition, so its formulation can contain errors or reasoning gaps, but these are obviated by the precise results that the algorithm provides.

H. The contradiction that reaches the highest weighting is called essential contradiction, since it contributes most to the solution of the multi-variable problem raised.

I. For a better determination of the solution, the essential contradiction is combined with the supplementary contradictions, which are determined by the preferred TRIZ engineering parameters, corresponding to the row and column of the specific matrix with the highest cumulative weight of contradictions, based on the quantification criteria already indicated.

J. The deliverables available with the TRIZ & TOC tool are as follows:

1) Specific matrix of contradictions.

(2) A prioritized list of inventive principles, containing first those of essential contradiction, plus a non-repetitive combination of inventive principles from three main supplementary contradictions (WSC) and

the five most significant inventive principles. The resulting set has proved to be able to propose a quick and assertive solution.

3) Table of Essential Contradiction and Supplementary Contradictions.

4) Prioritized list of weighted inventive principles (WIP) of the specific matrix.

5) Prioritized list of weighted contradictions (WSC) of the specific matrix.

Open TRIZ Second Wave TRIZ & TOC TOOL is a structured language proposal for innovation in multi-variable problems of any field of human development, which is validated with the results obtained.

Open TRIZ Second Wave: TRIZ & TOC TOOL can be applied at any stage of the innovation project:

¬ Conceptual solution to latent needs, problems, opportunities and ideas

¬ Subversive analysis of the design for the conceptual solution

¬ Resolution of problems and improvement of the deficiencies of operation of the prototype.

¬ Subversive analysis of the engineering design of the accepted solution.

¬ Troubleshooting and deficiencies startup of the innovation project.

¬ Solution to problems and deficiencies of the equipment or system in operation.

4. "RCA + EC" DIAGRAM FOR PROBLEM FORMULATION

This "RCA + EC" diagram is based on a joint application of two management tools: RCA +: ROOT CONFLICT ANALYSIS plus & EC: EVAPORATION CLOUD (RESTRICTION THEORY) and applies to a single object.

4.1.- Select Object

To formulate "RCA + EC" diagram, identifying the problem is probably an easy task, but defining the "object" to apply is not too obvious. Using the substance-field diagram, select "Object" S1 or S2, not both. See Fig.3.

As a general rule, it is convenient to identify the master object between S1 and S2. It may also be necessary to evaluate S1 and S2 in separate analyzes. Then select the best result.

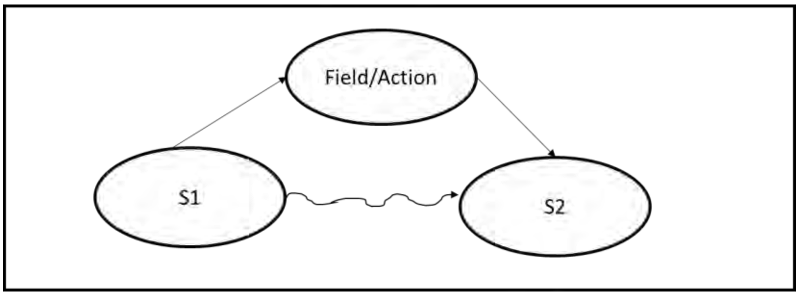


Fig. 3 Substance-field diagram

Another important aspect to consider is that the RCA + EC diagram is formulated depending on the time of the problem to be solved and in the space involved at that time (it is happening here and now). Another time and space is another problem and requires another RCA + EC diagram.

4.2.- Tools to construct the diagram "RCA + EC"

A) RCA +

Root Conflict Analysis (RCA +) is a relatively new addition to TRIZ's set of tools and techniques that aims to help manage the complexity of inventive problems by identifying the contradictions that make up a problem and the relationships between these contradictions.

B) EC

EC, Theory of Restrictions evaporation cloud (TOC), is used following the concepts presented in [3], which allow to determine positive and negative effects affecting an objective function and how the logical relationships between them should be. See Fig. 4.

4.3.- Steps in the "RCA + EC" diagram

Step 1: Establish the goal or goal function you want to achieve, such as solving a problem or capturing a good opportunity.

Step 2: Construct the substance-field diagram for the indicated objective function and select the object that has a significant negative effect. The RCA + EC diagram applies to this single object.

Step 3: Determine the actual difficulties that exist and are the causes of the problem. Use Ref. [2] and the recommended connection rules to construct the conflict resolution diagram (RCA + EC).

STEP 3.1 Indicate in general terms the difficulties that should not exist to achieve the desired objective function and begin to draw the RCA + EC diagram in descending order.

STEP 3.2 "Ask the question" What causes this effect to occur? "To find all the causes of the negative effect. What is the problem?

STEP 3.3 "After identifying a cause in Step 3.2, check whether this cause is the only condition that is sufficient to produce the negative effect. If necessary, draw other causes."

STEP 3.4 "Ask each cause if it also produces a positive effect. A cause that produces both positive and negative effect identifies as a contradiction."

Both negative and positive effects should contribute to the same objective function, see step 1.

STEP 3.5 "For each negative cause present in the diagram continue to ask the question" What causes this effect? "Build a Tree Cause-and-Effect diagram from top to bottom."

STEP 3.6 "For each newly described cause, which is indicated as an underlying negative effect, check again whether it´s the only cause that creates the negative effect or if there is another."

Step 4: Identify a physical requirement or variable and its condition that is the root cause of the negative impacts indicated in Step 3.

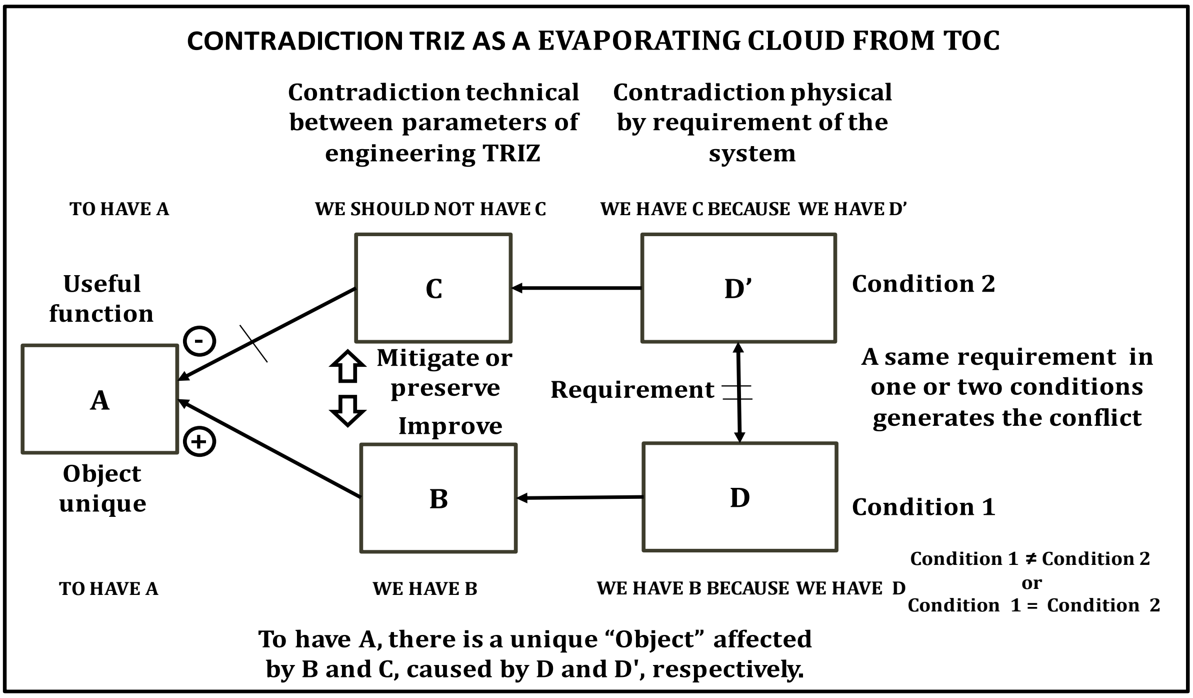


Fig. 4 Evaporation cloud diagram applied to TRIZ.

Step 5: Draw on the RCA + EC diagram the positive effects or opportunities that are generated from the requirement or from the identified physical variable, either in the same or different condition. Put on the top other positive effects that are deduced from the previous ones until it fulfills the objective function or goal.

Step 6: Verify that all connections made are true, meaning, they make logical sense in the analyzed technical and physical context, using the logical sequence shown in Fig.4

Step 7: Review all negative and positive effects and find out which TRIZ engineering parameters can be associated. It is possible that some effects can only be transitive relationships between the effects assigned to the TRIZ parameters.

Step 8: If all the above steps are met, we can identify the contradictions that affect the objective function or goal we have stated.

Step 9: indicate with "+" the positive effects and with "-" the negative effects See Fig. 5.

A well formulated problem by the RCA + EC diagram is a solved problem.

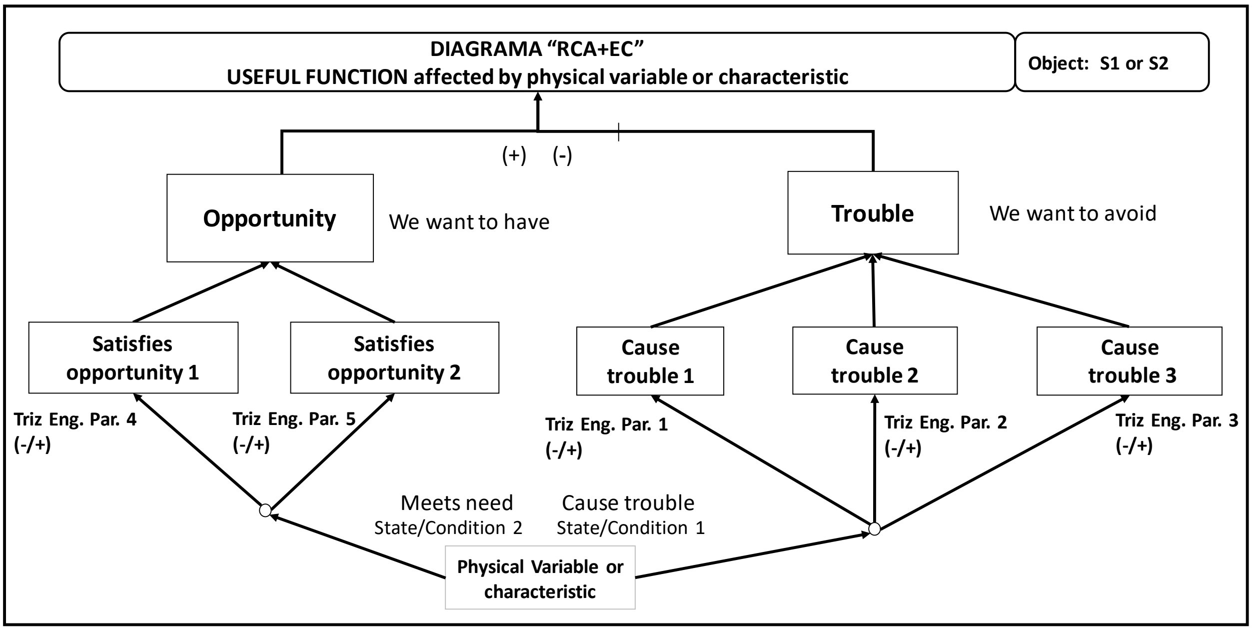


Fig. 5 General structure RCA + EC diagram.

Causes of troubles and opportunities that are satisfied are presented in the diagram in general, without indicating their relations, and, or, dependent or independent. The multi-variable analysis solution normally covers all these conditions.

5.- AATRIZ, ALGORITHM TO THE TRIZ SOLUTION

According to Albert Einstein's message, the "RCA + EC" diagram represents the formulation of the problem, which is more essential than its solution.

To find the solution, if we have up to 5 TRIZ engineering parameters, this represents 20 possible contradictions to be analyzed. This is because an engineering parameter associated with a negative effect always has its mirror effect or positive inverse.

Given the multiple possible contradictions and the time required to analyze each of them, a reasonable hypothesis was presented that would allow an accelerated and assertive identification of the main contradictions that solve in large part the problem studied. The objective is to find the essential contradiction whose solution solves the problem.

Under an abductive analysis, hypothesis are postulated to discover the essential contradiction that provides maximum benefit with minimal changes.

i. The algorithm weights each inventive principle differently according to the position and number of times it is used in the specific matrix, with a different weighting factor for each possible position: first, second, third and fourth. The result is a prioritized order of weighted inventive principles (WIP).

ii. The algorithm weighs the contradictions of the problem-specific matrix (WSC), based on an empirical mathematical function that applies to the already weighted inventive principles involved in each contradiction.

HYPOTHESIS:

The essential contradiction is the one that reaches the maximum weighting Fij (repetition, position), applying a mathematical algorithm that weighs the inventive principles that each pair of TRIZ engineering parameters identified, based on the number of times it is repeated in the contradiction matrix and according to their relative position in each specific contradiction (defined by the empirical rule to evaluate up to 5 engineering parameters). The detail of the applied algorithm is intellectual property, only fast and assertive solutions obtained are shown. Algorithm will be available at www.aatriz.cl in September 2017, remembering that it only supports thinking and does not replace it.

In addition, to support the search for the specific solution in the contradiction matrix it is convenient to consider the relationship between separation principles and solution strategy with the inventive principles, as proposed in [4].

6. - TRIZ &TOC TOOL APPLICATIONS

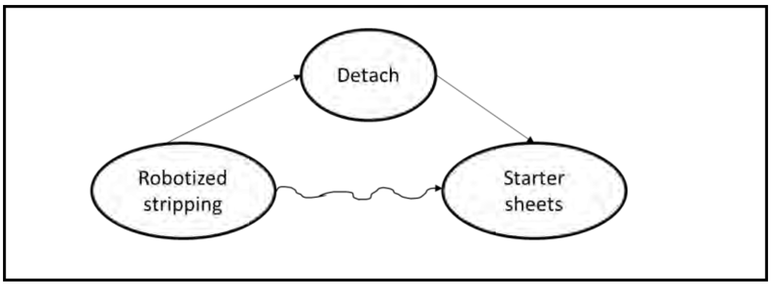
The proposed systematic operational innovation model has been successfully tested in several cases. Some examples are given below and the specific solutions for cases (a) and (b) can be seen in point 7.

A. EFFICIENT ROBOTIZED STRIPPING MACHINE Affected by sheet adhesion
B. MAXIMIZING THE TRANSPORT BUSINESS BY FERRY Affected by the risk of capsizing by the entrance of water into the cargo space.
C. PERSONAL SAFETY AT WORK Affected by the pressure of business results.
D. CONTINUOUS ELECTRIC GENERATION WITH FIXED MASS Affected by gravity.
E. ADMINISTER MEDICATION TO THE BRAIN affected by blood-brain barrier
F. COMPETITIVE OFFER FOR BID affected by quality of budget
G. INCREASING FUSION OF CONCENTRATED COPPER affected by capability of operator with high demand
H. DRINK COFFEE IN PLASTIC VESSEL affected by hot coffee

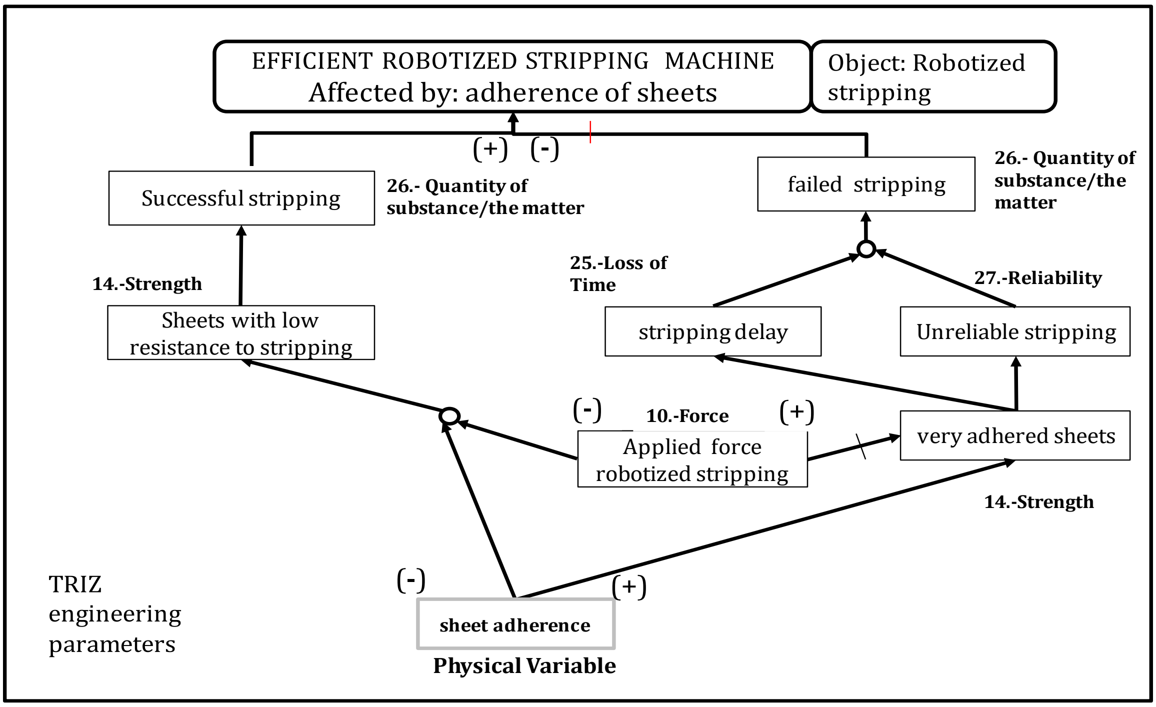
7.- EXAMPLE OF APPLICATION

7.1.- EFFICIENT ROBOTIZED STRIPPING MACHINE Affected by adherence of sheets.

Subfield-field Diagram



RC+EC Diagram



AATRIZ algorithm

SPECIFIC CONTRADICTIONS MATRIX							
Atenuar o preservar / Mejorar	Ref.	26.- Quantity of substance/the matter	25.- Loss of Time	14.- Strength	10.- Force (Intensity)	27.- Reliability	∑ Fij per row
26.- Quantity of substance/the matter	Inv. P.		35 38 18 16	14 35 34 10	35 14 3	18 3 28 40	
	Weight	F11 = 0	F12 = 2.649	F13 = 6.746	F13 = 8.457	F13 = 3.197	21.049
25.- Loss of Time	Inv. P.	35 38 18 16		29 3 28 18	10 37 36 5	10 30 4	
	Weight	F21 = 2.649	F22 = 0	F23 = 9.858	F24 = 1.386	F25 = 2.315	16.207
14.- Strength	Inv. P.	29 10 27	29 3 28 10		10 18 3 14	11 3	
	Weight	F31 = 3.630	F32 = 19.634	F33 = 0	F34 = 20.000	F35 = 4.073	47.337
10.- Force (Intensity)	Inv. P.	14 29 18 36	10 37 36	35 10 14 27		3 35 13 21	
	Weight	F41 = 5.178	F42 = 2.437	F43 = 7.521	F44 = 0	F45 = 3.885	19.021
27.- Reliability	Inv. P.	21 28 40 3	10 30 4	11 28	8 28 10 3		
	Weight	F51 = 2.853	F52 = 2.315	F53 = 2.792	F54 = 10.327	F55 = 0	18.287
∑ Fij per column		14.309	27.035	26.917	40.170	13.470	

First option for improvement — Preferential field of improvement — Secondary improvement options

The essential contradiction is 14 Resistance and 10 Strength (Intensity).

The supplementary contradictions are: 14 Resistance & 25 Loss of time; 27 Reliability and 10 Strength (Intensity); 26 Amount of substance / matter & 10 Strength (Intensity); 14 Resistance and 27 Reliability.

APPLIED SOLUTION (WIP)

Essential inventive principles

10 Preliminary action (1): Perform, before necessary, the required change of an object (totally or partially) → **Prior to partial stripping.**

18 mechanical vibrations (7): make an object oscillate or vibrate → **vibrating hammer.**

3 local quality (5): Make each part of an object function in the most suitable conditions for its functioning → The solution must be localized, the starter sheets produced must be of adequate quality and each part must perform a useful and different function.

14 Sphericity - Curvature (4): Instead of using rectilinear parts, surfaces or shapes, use curvilines → Selection of suitable position of the vibrating hammer that causes a slight curvature to facilitate detachment.

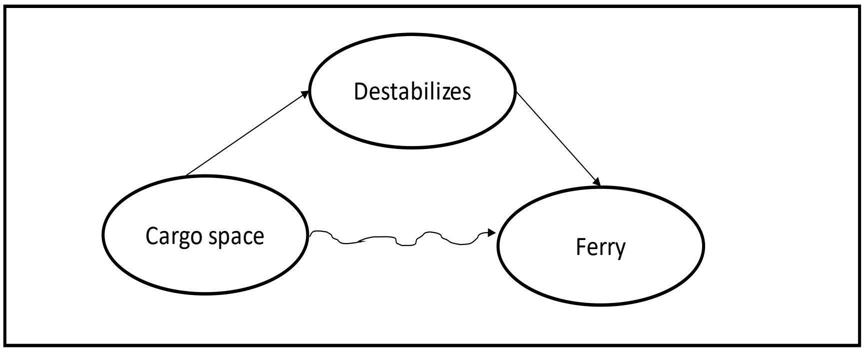
Supplementary inventive principles

35 parameter changes (2): Change the degree of flexibility of the blades → The flexibility to take off the blades is done with a vibrating hammer.

29 pneumatic and hydraulic (3): Use gas and liquid parts of an object instead of solid parts. → The vibrating hammer is controlled by pneumatic control.

7.2.- MAXIMIZING THE TRANSPORT BUSINESS BY FERRY Affected by the risk of capsizing by the entrance of water to the cargo space

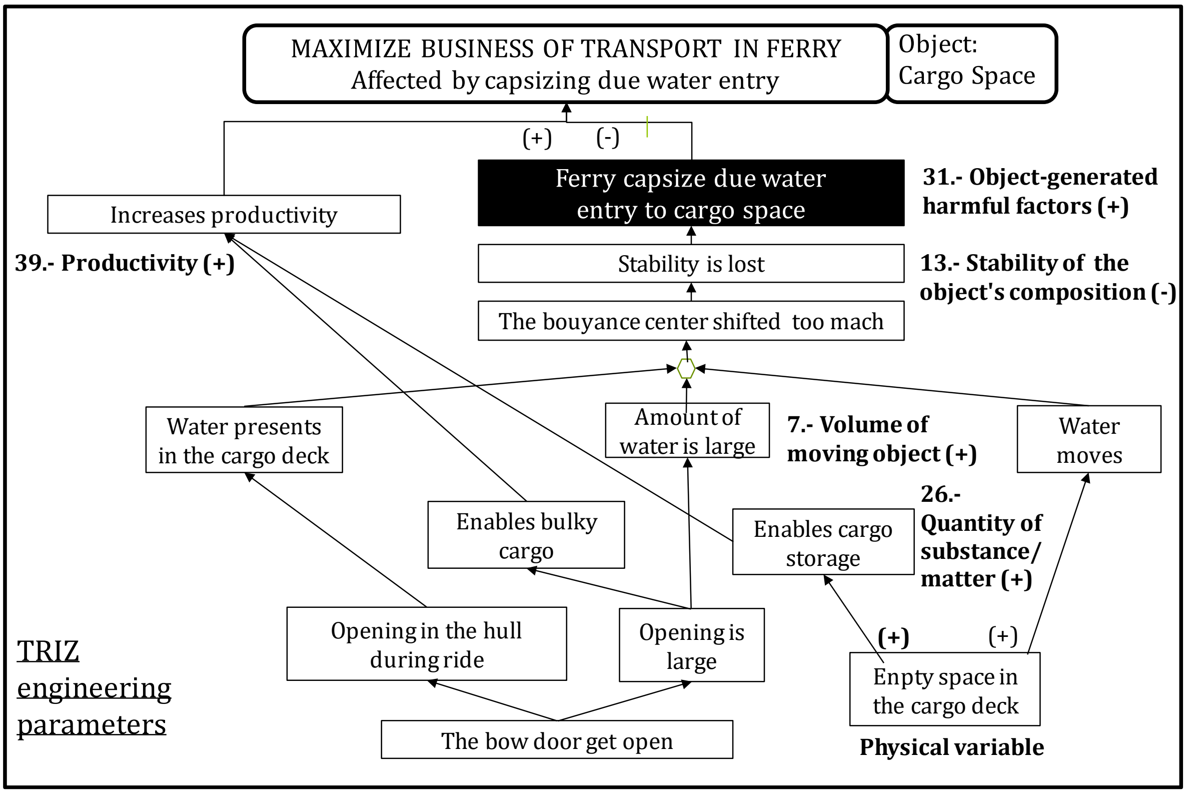
Subfield-field Diagram



RCA + EC Diagram

The essential contradiction is 13 Stability of the object´s composition and 39 Productivity.

The supplementary contradictions are: 26 Quantity of substance / matter & 13 Stability of the object´s composition; 39 Productivity and 3 13 Stability of the object´s composition; 26 Amount of substance / matter and 31 Harmful factors generated by the object.



AATRIZ algorithm

SPECIFIC CONTRADICTIONS MATRIX							
Atenuar o preservar / Mejorar	Ref.	7.- Volume of moving object	13.- Stability of the object's composition	26.- Quantity of substance/the matter	31.- Object-generated harmful factors	39.- Productivity	∑ Fij per row
7.- Volume of moving object	Inv. P.		28 10 1 39	29 30 7	17 2 40 1	10 6 2 34	
	Weight	F11 = 0	F12 = 3.322	F13 = 1.264	F13 = 4.894	F13 = 3.656	13.137
13.- Stability of the object's composition	Inv. P.	28 10 19 39		15 32 35	35 40 27 39	23 35 40 3	
	Weight	F21 = 2.894	F22 = 0	F23 = 6.847	F24 = 4.285	F25 = 20.000	34.025
26.- Quantity of substance/the matter	Inv. P.	15 20 29	15 2 17 40		3 35 40 39	13 29 3 27	
	Weight	F31 = 4.158	F32 = 18.132	F33 = 0	F34 = 10.630	F35 = 5.193	38.114
31.- Object-generated harmful factors	Inv. P.	17 2 40	35 40 27 39	3 24 39 1		22 35 18 39	
	Weight	F41 = 6.204	F42 = 4.285	F43 = 2.210	F44 = 0	F45 = 4.577	17.276
39.- Productivity	Inv. P.	2 6 34 10	35 3 22 39	35 38	35 22 18 39		
	Weight	F51 = 3.656	F52 = 12.794	F53 = 3.403	F54 = 4.577	F55 = 0	24.431
∑ Fij per column		16.912	38.532	13.725	24.387	33.427	

First option for improvement — Preferential field of improvement — Secondary improvement options

APPLIED SOLUTION (WIP)

Essential inventive principles

23 Feedback (11): Introduce feedback (back referring, cross-checking) to improve a process or action. → **Measure the water inflow**.

35 Parameter changes (1): Change the physical state of an object (for example, to a gas, liquid or solid) → **Change the physical state of the load space.**

40 Composite materials (12): Change from uniform materials to composites (multiple). → **Change the air from the cargo space to composite materials.**

3 Local Quality (3): Have each part of an object perform a different and useful function. → **The empty space must fulfill a different function from the occupied space.**

Supplementary inventive principles

15 Dynamics (2): Divide an object into parts capable of moving with each other, make it movable or adaptable → **The load space must be adaptable depending on whether water enters the interior.**

17 Another dimension (4): Use a multi-story arrangement of objects instead of a single-story arrangement. → **Use multiple objects in the cargo space.**

28 Mechanical Replacement (5): "Replace a mechanical medium with a sensing medium use electric, magnetic, and electromagnetic fields to interact with the object → **Install the water sensor in the cargo space.**

Solution that complies with this statement is shown in [2].

8.- CONCLUSIONS

The developed model shows to be assertive and fast to solve multivariable problems of innovation, joining TRIZ & TOC instruments that are enhanced among them and, in addition, demonstrates the importance of the formulation of the problem as a key aspect to find the solution, through the "RCA + EC" Diagram presented.

We can say that a well formulated problem is a problem solved. The AATRIZ algorithm fulfills the function of giving a quick orientation towards the solution and allows to perform sensitivity analysis in the formulation, design and monitoring of the implementation of the selected solution.

The TRIZ & TOC tool helps the massive use of TRIZ, addressing the problem from the social and human context that facilitates its understanding and application.

Considering the previous conclusion, the applied model has allowed to analyze many cases quickly and from there arises an urgent need to update the description of the parameters and principles of invention engineering, this, since the current descriptions explain a specific application, for example Intensity of lighting. But conceptually we have appreciated that it is generally applicable to the field intensity emitted by a substance / object. There are several examples as this.

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OPPORTUNITIES FOR INTEGRATING TRIZ AND IT PROJECT MANAGEMENT FOR ALIGNMENT IT – BUSINESS

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Abstract

The paper is based on the author's years of studies on the failure factors in custom software development projects. The low success rates in IT projects combined with the fact that functionalities of IT systems are so widely used in organizations, inspire researchers to look for causes underlying this situation, as well as for the ways to change it. TRIZ – a theory of inventive problem solving, when correlated with innovations, offers both these opportunities. The paper shows a line of reasoning in support of applying TRIZ in IT projects and highlights the resultant benefits. The study emphasises those shortcomings and deficiencies of the IT project management practice that are relevant to project success or failure. Furthermore, the author proposes how these weaknesses of IT projects can be modified or eliminated by using some elements of the TRIZ approach.

Keywords: Project Management, TRIZ, ARIZ, Problem Solving, Software development.

Introduction

Information systems play a crucial role in knowledge-based and innovation-stirred economies. Over the last decade, there has been a systematic increase in IT project implementation in companies [15, 16, 11, 12]. At the same time, a low rate of fully successful IT project implementations has been noted, alongside the problem of the latter not being tailored to the client's actual needs and that of inefficient communication within the IT manager – IT team – client triangle [5, 12, 16]. These observations pushed the worlds of business and science alike to undertake a multifaceted search for the causes and solutions within this realm, with special focus at the outset on technical aspects and the sheer methodology of project implementation. This approach, however, did not lead to any improvement in the assessment of success rates pertaining to IT projects. Next, following the analyses performed for the renowned International Journal of Project Management and Project Management Journal by Crawford, Pollack and England from 1994 to 2003 [3] and by Gemünden between 2000 and 2011 [6], the soft factors of IT project management gained ground in the studies. Among the factors enumerated most often as both critical success factors and failure causes are: the awareness of the client's role, communication and managerial support.

Studies within this dimension have resulted in numerous recommendations, which, unfortunately, are no more than wishful thinking. There is still no mutual understanding or cooperation between the creators of IT project products and their beneficiaries – the companies the projects are carried out for. According to reports on information systems, most enterprises use only about 10% of program functionalities to a significant extent [5]. Business expects IT to be more and more flexible. So claim international companies offering most comprehensive IT solutions, providing support for software management, incident management, problem management, configuration management, change management, version management and availability management.

In the meantime, also the perception of IT project success has evolved from the classic project triangle (i.e. time, budget, scope) [2] into a client inspired success and failure discourse [7]. In these circumstances a dialogue is rightly expected between the IT team and the client for more suitable products of the IT project in question. For this dialogue to be possible one needs proper awareness, space, common ground for mutual understanding and commitment of both parties. The literature of the subject and the author's IT project research indicate that the awareness of the need for this kind of dialogue is increasing. What is missing, however, is the common ground for understanding. It is a challenge for researchers to attempt to find a dialogue based language for as differing professional groups as the IT team and business.

The purpose of this paper is to highlight some key methodological, organisational and product-related aspects of IT project management. In this context, the focus is on the need for greater integration of project management stages and processes with the actors involved in these projects: the recipients of customized IT systems. The analysis is based on studies carried out by the author in the years 2012-2015, using the non-structured interview and participatory observation methods. The subject of interest were custom software development projects in the Polish SME sector. The studies revealed an evident need for creating mechanisms that would form a core mechanism supporting the integration of project management processes with the organizations' business processes, project deliverables – IT systems – with the real needs of organizations, a need for building a common space of collaboration between IT system developers and recipients (clients). The paper shows the potential applicability of TRIZ to the problems referred to above. It proposes, how the rules and tools of this methodology can be used in the key areas of IT project management process, where its consistency with the organization's needs is determined.

1. Key aspects, deficiencies and shortcomings of IT project management

Any IT project, when implemented in an organization, affects the company business processes directly. The organization's cohesion is verified in terms of the logic of actions, as well as in the aspects of its organizational culture. This cohesion, as the author's studies show, translates into the future perception of the IT project success [17].

Project management maturity of organizations

When analysing the important aspect of organizations project management maturity, the following levels can be distinguished [10]:

- Level 1 – initial – the organization's project management process is chaotic;
- Level 2 – managed – the project management process is planned and enforceable; plan execution is evaluated and corrective actions are taken in response to any variances; adequately skilled employees are appointed to implement the project;

- Level 3 – defined – close to Level 2 in its nature, but projects are managed proactively, i.e. processes are more actively modified and improved;
- Level 4 – quantitatively managed – project management processes are measurable, controlled and can be benchmarked against other projects;
- Level 5 – optimizing – the organisation / team gives attention to process improvement.

In the organizations demonstrating a lower maturity level, the expectations with regard to IT projects are less realistic, while project execution is more difficult, with less chances for success.

IT project objective

The next key aspect of IT projects is to define the IT project objective and evaluation criteria that will determine the process of project selection, as well as the future perception of the project as a success or a failure. Figure 1 shows the sequence of decisions used in the IT project management practice.

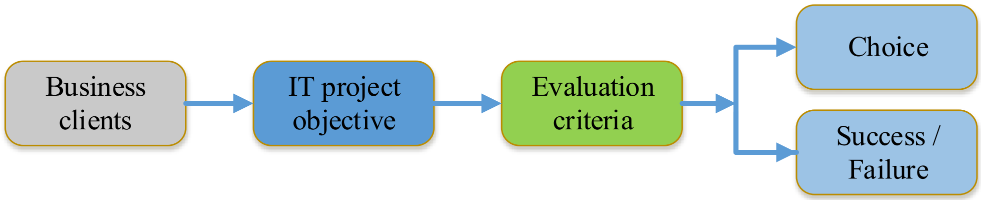

Fig. 1. Sequence of decisions in IT project management

The objective of an IT project is often determined by the following classification, where projects are intended to:

- bring additional benefits (increase the profits),
- offer new business opportunities,
- reduce costs,
- prevent potential losses (reduce risks).

As a result, the IT project deliverable – an IT system – is inconsistent with the organization's strategic goals or it does not solve the organisation's key problems.

In the IT project management practice, whichever methodology is used, similarly as in the IT project feasibility study, any environment and intervention logic analysis takes place only after the project objectives are identified. This sequence generates many errors and difficulties that occur in later phases of the project.

IT project feasibility study

The fact that an IT project feasibility study is ignored or misunderstood, is a serious problem in IT project management. By definition, it should verify whether the IT project is justifiable and whether it meets the organization's needs. Furthermore, it should propose more than one IT solution. The study should evaluate practicability, instead of justifying a single solution proposed. The project sponsor's purpose is to make a decision. According to the scenario-based management and systemic analysis methods, the decision-maker needs to have a choice, otherwise being no decision-maker at all. To make a choice, the decision-maker needs to know at least two possible solutions and the risks they involve. Yet, such studies are not often performed in the project management practice, unless the pre-defined administrative procedures require so (e.g. in the EU co-funded projects). Moreover, most typically, only one solution is presented.

Furthermore, an IT project feasibility study should present the initial or the current state, the planned state and an ideal one (Fig. 2).

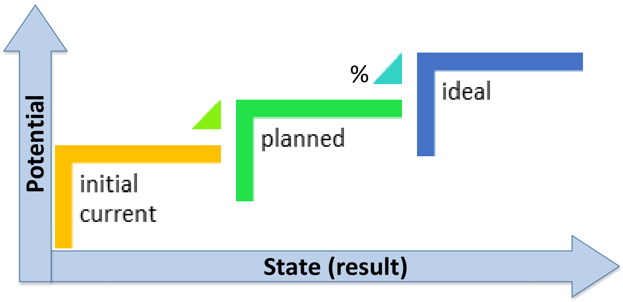

Fig. 2. IT project feasibility study

Establishing the so-called ideal state is often neglected in IT project management. Usually, the initial or current state is analysed, as well as the planned one. In IT projects, the current state is the situation where the project improves or expands a system and the initial state – when a system is created from the very beginning. As regards the planned state, it is extremely important to define an ideal state. An ideal state is an ideal model, i.e. a maximum limit, but theoretically achievable. It is a reference point – a benchmark for measuring (in percent, for example) the progress we wish to achieve. Without knowing the ideal state, it is impossible to assess risks of the planned state correctly, as the boundaries of action or the cost-benefit proportions are not known. Without creating the ideal state, we do not have a model of what is to be improved, we do not know any theory that describes the phenomenon or the situation – we may not know, for example, that the correlation is a strongly non-linear one and that the easily achieved current state is positioned on the breakdown point of this correlation curve. It is a typical situation, where heuristics are fatal for the project. This is why projects that are designed using trend analysis and are based on previous experience may fail.

Estimating IT project benefits

Estimating the potential benefits of IT projects is one of the greatest evaluation problems. A situation where IT engineers are attempting to perform the estimation on their own, without involving the user organization, is a classic mistake. This is when IT project deliverables are not duly linked to organization's business goals. The potential benefits of an IT project implementation should be estimated by the IT project recipients – best, if they are aware of the expectations the project should meet. If this principle is not followed, final evaluation criteria will be set incorrectly. Hence the paradox, where the IT specialists involved in the project celebrate successful completion of the task, while the users – system recipients – perceive the project as a complete failure.

2. The potential utility of TRIZ in IT project management

TRIZ has been designed with an intention to improve product quality. It addresses not on product proper, but the process associated with its development too. Hence, those of the analytical tools provided by TRIZ that are applicable to processes, can also be used in project management [8]. This approach can be used when defining the best structure of an IT project, for example. The present study proposes applying TRIZ and its analytical tools to IT project management.

This chapter will address the gaps and weak aspects of IT project management described in the previous section. It will propose modifications and changes to the IT project management process, so as to benefit from the opportunities offered by the TRIZ approach.

It is a frequent mistake in IT project management, that the focus is on the following questions:

- Are we executing the project correctly?
- Is the project being delivered on time and on budget?
- Do project stakeholders know, what they should be doing?

TRIZ analytical tools can help upgrade these questions to a different level and to re-define them in the following way:

- Are we working on the right project?
- Are we investing in the right area?
- How can we use our resources, to be competitive?

This re-definition is even more important, if the organization's project management maturity level is low. Thereafter, we can move to more detailed questions that will help us specify the scope of problems – the IT project focus areas. TRIZ analytical tools will facilitate the process of answering these questions, so as to reveal the root causes of problems. As the next step, the so-identified problems can be addressed using TRIZ patterns and problem solving techniques [4].

The issues of client needs management and scope creep can be mitigated by means of TRIZ procedures in the following way:

- looking at IT project deliverables as tools to be used with respect to organization's business needs,
- looking at organization's business needs from the angle of problems that have been identified,
- identifying organization's problems defines all IT project products,
- IT project products determine the project scope.

An approach like this will ensure the co-ordination of business processes and IT project deliverables.

When using TRIZ methodology, it is possible to replace the classic decision-making sequence presented in Fig. 1 with the model presented in Fig. 3. The project objective definition is transferred to a later stage, while priority is given to identifying problems of the client. It may even turn out that some of the solutions proposed will not have the form of an IT project. A situation like this will occur, if problems can be addressed by eliminating some business processes that previously required computer-based solutions. On the other hand, the solutions that involve an IT project will automatically include the project objective that has emerged as a result of problem identification. This is how TRIZ methodology can contribute to making an IT project a solution to the problem that has been identified.

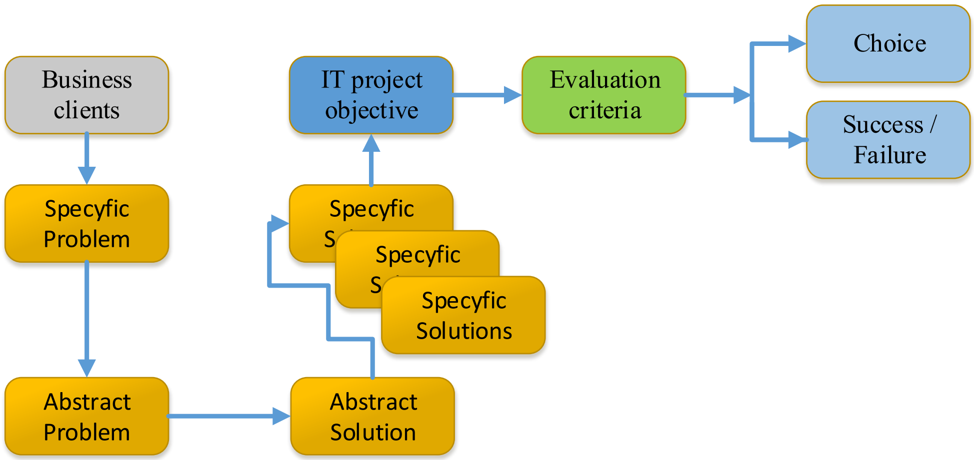

Fig. 3. Sequence of decisions in IT project management combined with TRIZ

Furthermore, the proposal developed based on the multiple specific solutions strategy required by TRIZ, following the stage of solution abstraction, is consistent with the IT project feasibility study recommendations. This approach, adopted from TRIZ – multiple specific solutions – can reinstate the principles that have been ignored in IT projects.

The TRIZ methodology reorients an IT project from responding to consequences of problems, to responding to root causes of problems in the organization. It is a crucial redefinition of the IT project role. This alteration may become a key factor in eliminating such common weaknesses of the IT project management process, as the incorrect identification of user needs, the scope creep, the unused system functions or the technical debt [9].

This approach will require including a pre-phase in the IT project management, to identify organization's specific problems the IT project is expected to address. This phase will enable better specification of the IT project deliverables and will support the IT–business alignment.

TRIZ offers a number of approaches oriented towards problem identification – from benchmarking, through functional analysis, flow analysis, causal chain analysis, to analysis of trends in evolution and trimming [1]. By using the procedures and tools that correspond with these approaches, it is possible to identify problems and their sources, e.g.

- Functional analysis – harmful functions, useful functions excessively or insufficiently performed (system flaw),
- Flow analysis – system flaws,
- Causal chain analysis – key defects of the system.

Thereafter, the IT project deliverables can be oriented towards elimination of these sources of problems (Fig. 4). With a decision-making system organised in this way, a decision to launch an IT project will not generate any random changes, but will lead to the most ideal solutions [13].

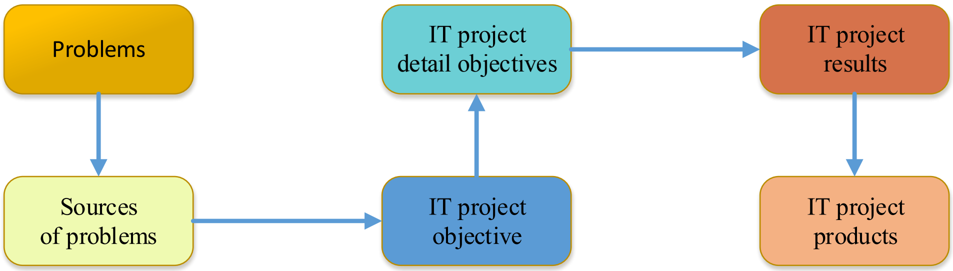

Fig. 4. Approach to IT project products in IT project management combined with TRIZ

Ideality is the key concept of TRIZ [14]. Hence, TRIZ solves the problem of defining the ideal state in the IT project feasibility study. This phase is often neglected, due to difficulties with calculations. This is where TRIZ comes useful, as defining ideality is an element of ARIZ. Thus, owing to TRIZ, the proposed IT project deliverables can be guided from the planned towards the ideal (using IT project management methodologies). Moreover, this approach will eliminate the problem of unused functionalities in IT systems, which is one of the most often reported IT project problems.

Starting with the TRIZ-based identification of the organization's problems and using this as a guide for defining the IT project deliverables solves also the problem of estimating benefits from the IT project. The list of defects – harmful and useful functions excessively or insufficiently performed in the organization, ranked and estimated on cost terms, as used in TRIZ, will enable specific calculations. The IT project deliverables directed towards elimination or modification of these functions can be assigned values computed using TRIZ – the IT project benefits.

What makes TRIZ particularly useful in IT project management is the possibility of structuring the process into four stages:

- identifying the scope of problems and subject fields – TRIZ analytical tools,
- generating ideas of solutions to the problems to be addressed – TRIZ patterns, problem solving techniques,
- selecting and implementing a solution – TRIZ analytical tools, TRIZ patterns, problem solving techniques,
- eliminating secondary problems that arise as a result of the solution – TRIZ patterns, problem solving techniques.

Figure 5 depicts a TRIZ-based diagram of IT project implementation. The diagram was developed in compliance with the fundamental TRIZ rule, i.e. striving to attain the ideal final result. The most important features of this solutions comprise:

- eliminating the flaws of the current (actual) state,
- preserving the advantages of the current state,
- introducing simple solutions,
- introducing no new flaws.

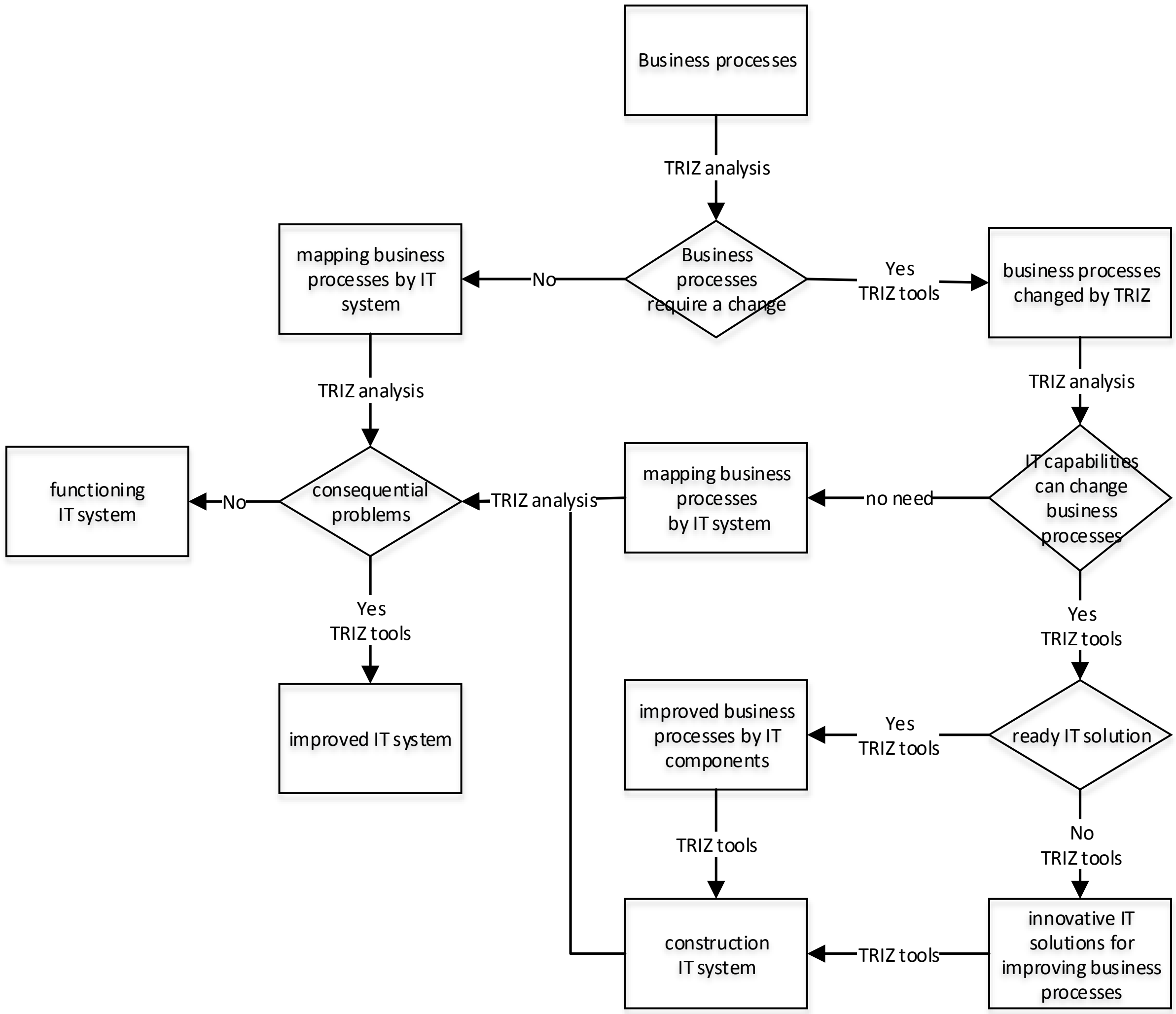

Fig. 5. TRIZ-based diagram of IT project implementation

TRIZ might become a core of the IT project management process, that would integrate problem-oriented modification of business processes with IT project deliverables and change management (Fig. 6). Such an integrated management would enable the incorporation of an IT project into the process of achieving a specific strategic goal and would maximize the resultant benefits.

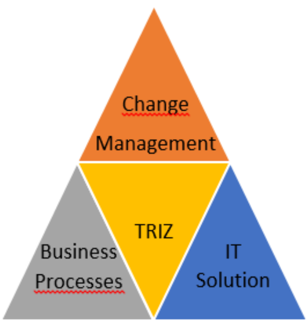

Fig. 6. TRIZ in IT project management

Source: own

The benefit will be achieved completely only when the delivery of business and IT capabilities is co-ordinated in time (products, services and changes to processes).

Business integration of project deliverables should occur at the right moment, thereby activating IT services (based on the IT project deliverables) and new or modified business processes based on the changes to business. The process described above cannot take place, if mechanisms connecting different elements of the system are not in place – IT solutions developed based on the identification of organization's problems.

3. Conclusions

At the current stage of work on the implementation of TRIZ into IT project management, TRIZ should be regarded as a methodology offering tools that enable changes to the critical areas of IT project management. TRIZ enforces the often neglected analysis of the way how the project user – the organization – operates and the need for adequate preparation (modification) of business processes prior to deployment of IT solutions. Such an approach offers an immense chance for enhancing the effectiveness of IT projects. What has to be done in this process, is to work out a path where TRIZ tools will integrate IT the management of IT projects with the modification of business processes, in order to improve the organization's performance. Some of the activities and recurring contradictions can be standardised, while project-specific elements will have to be analysed following a pre-defined procedure (sequence). These elements require extensive studies in the field of IT project management.

Although the history of TRIZ development in business and management is not long, the evidence of its effectiveness is substantial. The advantages of this methodology include its applicability to a wide range of problems, as well as its compatibility with other methodologies. These facts provide even stronger arguments for using this methodology to support other methodologies in their weakness areas. Just as it is the case with IT project management methodologies, where many similar problems occur irrespective of the methodology used: problems with properly identifying user needs, performing a rational analysis or dealing with the scope creep.

The idea of combining the scholarly realm of IT project management with systematic methods offered by TRIZ should gradually lead to the creation of IT TRIZ. To attain this, further studies should be conducted towards adapting the rules of TRIZ to both the IT project management and the creation and implementation of IT products. TRIZ methods are to be combined properly with the IT project management methodologies applied. Innovative rules largely pertaining to engineering disciplines should be interpreted in such a way that a decision can be made whether they are applicable to business processes and IT systems. In certain cases, such a transposition of the rules onto the IT project management domain can prove rather challenging and require some research work.

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OPTICAL CONTRADICTIONS IN TRIZ: A REVIEW

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Abstract

This paper suggests that it makes sense to consider physical contradictions in which two opposite optical properties are required from the same component as a separate type of physical contradiction, under the heading 'optical contradiction'. This is justified by the wide variety of optical phenomena that relate to light propagation in space and time as well as to light interaction with matter, the rapid development of optical engineering and technologies, and the existence of unique methods for solving optical contradictions, which take into account the wave nature of light. The paper reviews examples of optical contradictions from geometric, wave, laser, and other areas of optics. In addition, a few special methods for resolving optical contradictions are described. These methods are (1) separation in the radiation spectrum, (2) separation by polarization, and (3) separation in phases of the light wave. In optics, they can be more efficient than the general methods that TRIZ recommends for solving physical contradictions.

Keywords: TRIZ, contradiction theory, physical contradiction, separation principle, optical properties and phenomena.

1. Introduction

The concept of physical contradiction, which is one of the key concepts in modern TRIZ, describes a situation, wherein the same parameter needs to exhibit opposite physical properties (e.g., it needs to be thin and thick, heavy and light, hot and cold, etc.). In terms of mathematics, the physical contradiction represents an equation of a technical problem [1].

Among the physical properties of material objects, optical properties, which relate to light propagation in space and time, as well as to the interaction of light with matter, hold a prominent place. More than one fourth of the approximately 250 physical effects collected by Denisov et al [2] represent optical phenomena. As noted by Jensen [3], from 80 to 90 percent of the information that humans receive from the outside world is visual perception.

In optics, the term 'light' normally refers not only to visible light, but also to infrared and ultraviolet radiation, as well as to X-rays. Overall, it covers the wavelength range from 0.01 nm to 1 mm.

Due to a wide variety of optical phenomena and the rapid development of optical engineering and technologies, it makes sense to consider 'optical contradiction' as a special type of physical contradiction in which two opposite optical properties are required from the same component of a technical system. Additionally, this separation is justified by the existence of unique methods for resolving optical contradictions.

This paper is a review devoted to optical contradictions in TRIZ. Section 2 surveys examples of optical contradictions from geometric, wave, laser, and other areas of optics. Section 3 focuses on a few specific methods for resolving optical contradictions. These methods take into account the wave nature of light. In optics, they can be more efficient than the general methods that are recommended for solving physical contradictions by Litvin [1] and by Altshuller [4].

2. Optical Contradictions Solved Using General Methods for Resolving Physical Contradictions

In this section examples of optical contradictions from different areas of optics are presented. It is shown how these contradictions can be solved using general methods for solving physical contradictions, namely by separation in space and time as well as using system transitions.

2.1. Case Study 1: Gradient Laser Mirrors

The invention of the laser as a source of coherent optical radiation is, in itself, a result of overcoming the contradiction between quantum and classical physics. A necessary condition for laser generation utilizes an active medium with an inverse population of energy levels, which is known in quantum physics. In classical physics, though, the active medium cannot exist because at thermodynamic equilibrium, in accordance with Boltzmann distribution, the upper energy level population is always less than the lower energy level population[3].

Nevertheless, an active medium is not enough to build a laser. All specific properties of laser radiation are formed by an optical resonator, inside which light wave travels back and forth through the active medium [6].

Optical resonators used in conventional methods of generating high-power diffraction-limited laser beams are unstable resonators. Such resonators are especially effective in lasers with a high gain and a large cross-section of the active medium (e.g., in excimer and CO_2 lasers).

However, in order to ensure single-mode laser generation[4], the edge diffraction on the output mirror must be eliminated. This is because a light beam diffracted off the edge of a mirror causes energy to scatter over a wide angular range, and a small amount of radiation is scattered back into the cavity as a converging wave, as shown in Fig. 1. Since it remains inside the resonator for a long time, such a wave affects the laser mode structure and deteriorates beam quality.

[3]*The existence of non-equilibrium systems with population inversion was predicted in 1939 by Valentin Fabricant. Interestingly, in the 1920s Rudolf Ladenburg observed the so-called enhanced emission of gas discharges that corresponded to the non-equilibrium state of the system. Nevertheless, Ladenburg and his followers were too deeply steeped in Boltzmann's idea of thermodynamic equilibrium to make anything of their observations. (See review [5] and references therein for details.)*

[4]*A laser mode is defined as an electric field distribution which reproduces itself (apart from a possible loss of power) after a full trip through the resonator. (See, for example, Ch. 1 in the fore-quoted monograph [6].)*

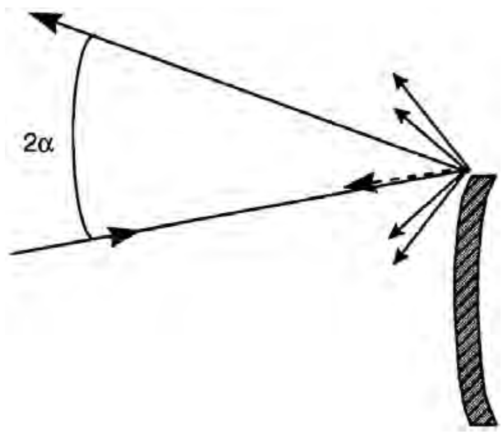

Fig. 1. Scattering of the diverging wave on the edge of the output mirror. Some radiation is scattered back into the resonator, yielding a converging wave [6]

Thus there is an optical contradiction: the reflectance of the output mirror should be high in order to maintain laser generation, but it should be low in order to minimize the diffractive effects at the mirror edge.

This contradiction is solved by a separation in space using the principle of a local quality. In substance, the mirror reflectance should be low only within a narrow operative zone wherein detrimental diffraction effects occur, namely, in the periphery region. Near the longitudinal axis of the resonator, the mirror reflectance can remain high.

The solution is a mirror, whose reflectance decreases smoothly from its maximum in the central zone to zero on the periphery. As an example, Fig. 2 shows a mirror with an ideally 'smoothed' edge, its reflectance distribution described by the Gaussian function.

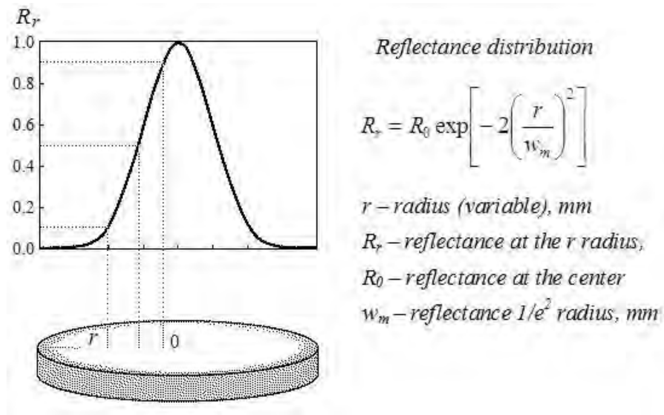

Fig. 2. Mirror with Gaussian distribution of reflectance [7]

There is, however, a secondary problem: how to make such a 'gradient' mirror? This can be solved by using multilayer dielectric coatings of variable thickness on a glass substrate. The reflectivity of components manufactured in this manner is determined by the effects of multi-path interference in multilayer thin-film systems [8]. Nowadays, gradient mirrors are commercially available and can be found in an increasingly large number of lasers [9].

2.2. Case Study 2: Automotive Rearview Mirrors Made of Chromogenic Materials

The main function of the automotive rearview mirror is to inform a driver of the situation on the road. As every driver knows, being able to clearly see pedestrians, bicycle riders and other vehicles depends on the characteristics of the rearview mirror. This mirror, however, also has a harmful function: to reflect bright light. The glare of bright lights from a following automobile, brilliant sunshine, and even the setting sun can blind the driver and cause a car accident.

Once again, there is an optical contradiction: the reflectance of the automotive mirror should be high in order to show the traffic situation clearly, but it should be low in order to prevent dazzling the driver.

This contradiction can be solved by separating the contradictory requirements in time because low reflectance is required only when there is glare from light reflected in the mirror.

One of the known solutions, suggested by Byker [10], involves temporarily changing the mirror's optical characteristics by using chromogenic materials. Currently, there are two major categories of reversible chromogenic materials: transition metal oxides and organic compounds. The commercially available chromogenic switchable mirrors surveyed by Lampert [11] are based on a stack of solid inorganic of $H_xWO_3/Ta_2O_5/NiO_y$.

A similar solution for eye protection has been proposed in auto-dimming glasses on a welding helmet. The safety welder's glass, patented by Masses [12], comprises an interference filter that transmits visible light and a combination of polarization filters and liquid crystal layers controlled by a light sensor to darken the glass quickly as soon as the welding arc is created.

Another important application wherein optical contradictions are separated in time is so-called 'smart windows' with thin-film coatings made from chromogenic materials that regulate the passage of light and heat into buildings while maintaining outward visibility [13].

2.3. Case Study 3: Maksutov Meniscus Systems

Observational astronomy started in 1610 when Galileo Galilei directed his lens telescope at the night sky. In 1668, Sir Isaac Newton suggested the mirror telescope wherein the light from a celestial object is received on a primary concave mirror and the real image of the object is formed in its focal plane. A secondary mirror directs the rays to the eyepiece on one side of the tube. In another arrangement, proposed by Laurent Cassegrain (Fig. 3), the secondary mirror reflects the beam back towards the primary, where rays pass through a hole bored in the center of the mirror and come to a focus just behind it [14, 15].

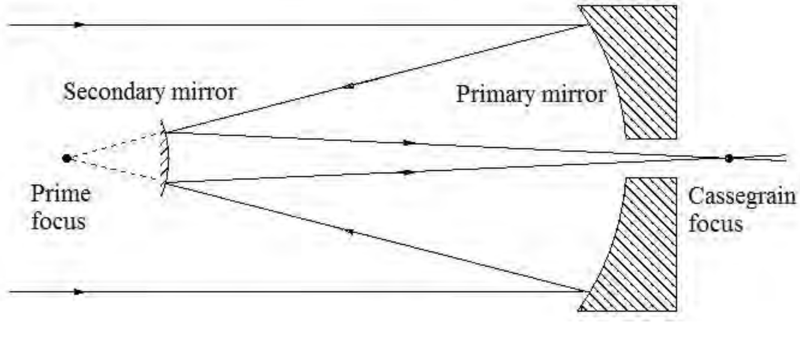

Fig. 3. The Cassegrain telescope [15]

Since mirrors use reflection rather than refraction to form an image, they are inherently free of the most destructive aberration – chromatism. However, they have monochromatic aberrations, which are caused by manufacturing imperfections in the optical components. For a long time, the only solution was to use aspheric mirrors, which are difficult and expensive to make.

The optical contradiction here is that the primary mirror of the telescope should be spherical in order to produce it easily and inexpensively, but it should be aspherical in order to eliminate spherical aberration.

Furthermore, the geometric properties of reflectors allow us to formulate another optical contradiction: the primary mirror of the telescope should be parabolic in order to eliminate spherical aberration, but it should be spherical in order to eliminate parabolic aberration, i.e., coma.

These contradictions cannot be solved by separating contradictory requirements in space or in time. Nevertheless, it is possible to use the system transition from a mono-system to a bi-system made from inverse components. This is what Dmitry Maksutov did in 1941[5]. By that time, aspherical Schmidt corrector plates were already well known [14]. Maksutov, however, was looking for a spherical optical component with an aberration equal to but opposite that of the primary mirror. Thus, he suggested using a meniscus with spherical surfaces [17, 18] as the solution. Fig. 4 shows Maksutov's modification of the Cassegrain telescope. The inner face of the spherical meniscus corrector has a small aluminized spot on it, which acts as the secondary mirror, redirecting the light through a hole in the spherical primary mirror[6].

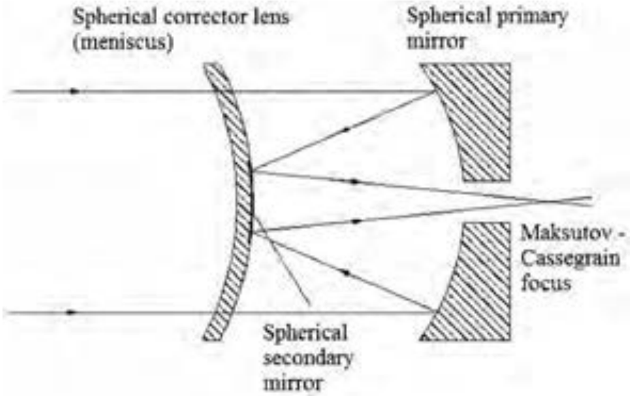

Fig. 4. The Maksutov – Cassegrain telescope [19]

This solution, however, does not involve specific methods for solving optical contradictions.

[5]*Some say that Maksutov did not resolve the above contradiction. This, however, refers to a technical contradiction for an inexpensive school telescope, as pointed out by Gerasimov [16]: (1) if a telescope tube is not covered with protective glass, the telescope will be inexpensive, but the primary mirror is unserviceable; (2) if a telescope tube is covered with protective glass, the telescope will serve for a long time, but it will be expensive. In our example, however, we are talking about the physical contradiction relating to the geometric form of the telescope's primary mirror.*

[6]*It was also found that achromatic menisci with $\Delta R/d \approx 0.7$, where ΔR is the difference of radii of curvature, and d is the thickness of the meniscus, introduce the same spherical aberration regardless of the refractive index of the glass from which menisci are made. This allows us to substitute one type of glass with another, leaving all structural components of the system unchanged.*

3. Special Methods for Resolving Optical Contradictions

In this section the wave nature of light is taken into account in order to solve optical contradictions. For that, we will use parameters that characterize light waves: wavelength, amplitude, polarization and phase shift. We believe that in optics this approach is more efficient than the general methods that TRIZ recommends for solving physical contradictions.

3.1. Separation in Spectrum

Let us return to the optical contradiction posed for the automotive rearview mirror: the reflectance of the automotive mirror should be high in order to show the traffic situation clearly, but it should be low in order to prevent dazzling the driver.

Using the reversible chromogenic materials discussed in Section 2 solves the contradiction in time, but this solution has a certain disadvantage: the switching time required to obtain the low reflectance can be rather long. Is there any solution with a 'zero' switching time? In order to find out, the relationship between the spectral characteristics of automotive headlamps and the spectral reflectance of mirrors has to be considered.

For example, the maximum radiation intensity of halogen automotive headlamps lies in the red or yellow region of the spectrum (wavelength range of 620-700 nm and 570-590 nm, respectively). Therefore, by reflecting only blue and green spectral components (in the range of 450-590 nm) while inhibiting red and yellow light (Fig. 5), it is possible to achieve effective eye protection against this type of glare while providing enough detailed information on the traffic situation. This solution was proposed by Pein [20]. In order to prevent dazzling by xenon headlamps, which generate blue lines at 405, 435 and 475 nm, the mirror reflectance should be minimal in the blue spectral region, as suggested by Makhin et al [21].

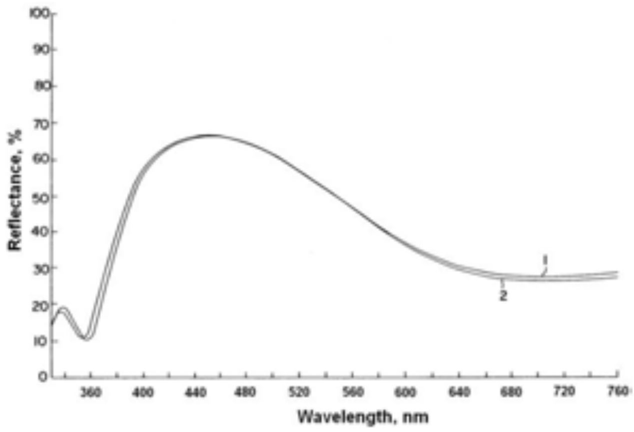

Fig. 5. Spectral reflectance of anti-glare automotive mirrors. 1 – plane mirror, 2 – spherical mirror [20]

In both cases, spectral variations of the mirror reflectance are provided by multilayer interference coatings on a glass substrate. The coatings are made from materials with alternating high and low refractive indices.

These examples demonstrate a powerful method for resolving optical contradictions: separation in spectrum.

Another example of using separation in spectrum relates to improving the energy efficiency of conventional incandescent light bulbs. Here, the optical contradiction is that the color temperature of a bulb filament should be high in order to increase the fraction of energy emitted as visible light, but it should be low in order to decrease the amount of electrical energy required to heat the filament. The solution presented by Bergman and Parham [22], involves depositing multilayer optical coatings on the outer surface of a light bulb. These coatings do not affect the visible light emitted by the filament, but reflect the infrared radiation back to the filament, thereby recycling its energy.

Multilayer interference coatings described here are also called 'dichroic filters' because they allow light of certain wavelengths to pass through while the light of other wavelengths is reflected.

Besides dichroic filters, there are other components that can be used in solutions that involve separation in spectrum, e.g.:

- absorptive and band-pass filters [23, 24],
- prisms [25],
- diffraction gratings [26],
- Fabry-Perot interferometers [27],
- other optical components [28, 29].

3.2. Separation by Polarization

Traditionally, the process for manufacturing integrated microcircuits includes exposing light-sensitive material, called a photoresist, on a semiconductor substrate to ultraviolet radiation. The light beam passes through a lithographic mask with slits and reaches the photoresist through a lens. On the surface of the light-sensitive layer, the lens forms an image corresponding to the mask pattern [30].

In order to make integrated circuits more compact, individual circuit elements must be located as close to each other as possible. To accomplish this, the width of the slits in the mask should be decreased; however, the narrower slits allow less light to pass through the mask to the photoresist. Moreover, the narrower slits increase the detrimental effect of scattering and absorption of radiation manifested in the mask. This results in a low contrast image on the photoresist layer.

The optical contradiction relating to this situation could be formulated as follows: slits in the mask should be narrow in order to decrease the size of individual elements of the circuit, but they should be wide in order to form a high-contrast image on the photoresist layer.

There is no solution for this contradiction within geometric optics; however, in a wave-optical approach we can find it quite easily if we consider light polarization [31-33].

Unpolarized light, for which there is no preferred polarization angle, can be thought of as a superposition of two states of polarization: *s*-polarization and *p*-polarization that have, respectively, perpendicular and parallel directions of the electric field vibration relative to the plane of light incidence. (See Fig. 6 for details.)

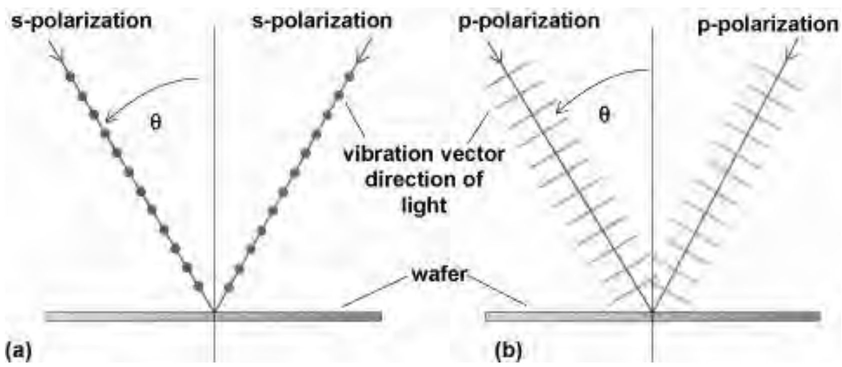

Fig. 6. Two states of polarization showing the vibration direction of the electric field for the two light rays incident on the wafer surface with an angle θ. (a) s-polarization has the vibration direction perpendicular to the plane of the figure, (b) p-polarization has the vibration direction parallel to the plane of the figure [33]

Only the p-polarized component of the light deteriorates image quality on the photoresist layer. With a polarizer placed before the mask only s-polarized light will penetrate, while the p-component of the polarization will be blocked. Such an arrangement minimizes scattering and absorption of light energy at the mask, and provides maximum contrast of the photolithographic image.

Another example of separating contradictory requirements by polarization relates to the personal hygiene mirror with a built-in light source. The problem is that the glare light reflected off the skin surface can impede the user from seeing his or her skin in detail.

So, once again, there is an optical contradiction relating to the suppression of light glare: the mirror reflectance should be high in order to let the user see his or her skin in detail, but it should be low to prevent glare reflected from the surface of the skin.

In order to find the solution, it is necessary to note the following effects:

1. Light reflection on the air-skin boundary. From 4 to 7 percent of incident light reflects back to the viewer at the boundary between air and skin. This specular reflected wave carries mostly information about the contour of the skin surface. For this light wave the polarization does not change.
2. Light absorption and scattering in deeper skin layers. The majority of the light flux enters the skin and is absorbed or is scattered back as diffuse reflected wave, which makes it possible to see color variations, pigmentation, hair follicles, blood vessels, and other details in deeper skin layers. As described by Anderson [34], when polarized light penetrates deeper into skin tissue, it is depolarized due to scattering.

The solution patented by Mullani [35], involves a polarizer in front of the mirror that blocks specular reflected radiation. At the same time, the diffuse reflected light passes through the polarization filter, thus producing an enhanced view of the skin surface.

It is worth pointing out that in non-optical applications polarization separation methods have also been used. For instance, in geophysics, the separation of wave field from crosswell seismic data into s-wave and p-wave for earthquake prediction has been suggested by Byerlee [36] and Liu et al [37].

3.3. Phase Separation

From ancient times, humans have wanted to see things far smaller than could be perceived with the naked eye. In conventional optical microscopes that magnify tiny objects, a contrasted image is formed when light is absorbed by the sample. However, many lightly stained, transparent or colorless objects (e.g., single-celled organisms, aquatic environment samples, etc.) do not absorb light and, therefore, cannot be seen with a traditional bright-field microscope.

Thus, we can formulate the following optical contradiction: light should be transmitted through the sample in order to make its details visible, but light should not be transmitted through the sample in order to provide a high contrast image.

Another approach can be found in dark-field microscopes, which achieve enhanced contrast through light scattering rather than direct transmittance and absorptance. Yet these microscopes do not completely resolve the contradiction because dirt and dust located along the light pathway distort the sample's image. Furthermore, the low light level means the sample must be strongly illuminated, potentially damaging delicate samples.

In order to obtain a contrast image in the transmitted light, Frits Zernike suggested using minute variations in the phase of the light wave passing through the object [38]. Although the human eye does not perceive differences in light wave phases, these differences can be converted into corresponding changes in amplitude that the human eye can distinguish. In microscopy, such a separation in light wave phases is called the phase contrast method[7].

Phase contrast makes it possible to visualize internal cellular components, such as membrane, nuclei, mitochondria, chromosomes, etc. Nevertheless, if the absorption is non-uniform within the sample cross-section, then the image observed with a phase-contrast microscope will be distorted. In recent years, several methods known as methods of quantitative phase-contrast have been proposed to overcome this limitation by separating the phase images from the absorption images [39, 40].

In Section 2 we discussed the advantages and drawbacks of unstable optical resonators for single-mode lasers with high power or energy. Owing to large diffraction losses, such resonators do not suit active media with low gain or small cross-sections. In contrast, in stable resonators the radiation is concentrated near the resonator axis, which allows for using active media with low gain or small cross-sections. Unfortunately, diffraction losses in stable resonators are small not only for the fundamental mode, but also for higher laser modes, which increases beam divergence.

In order to suppress higher laser modes in the stable resonator, a series of intracavity apertures arranged in a certain order have been suggested by Pax and Weston [41]. In this invention, the amplitude of the fundamental mode has a bell-shaped profile with smoothly tapered 'wings' that are partly cut by aperture edges. The disadvantage of this solution is that large losses are introduced by the intracavity apertures.

Thus, for the laser resonator, we can formulate the following optical contradiction. Intracavity losses should be small to assure laser generation in low-gain active medium, but they should be

[7] *For this invention, in 1953 Frits Zernike received the Nobel Prize in physics.*

large to suppress higher laser modes in the resonator and, therefore, to provide low beam divergence.

In a previous publication [42], it was shown how to resolve this contradiction using the phase separation principle. The proposed approach avoids the trial-and-error method used earlier in such cases. If the phase responses of both mirrors in a two-mirror resonator coincide with light wave phase distribution as shown in Fig. 7, then the light wave will represent the fundamental mode of the resonator. Thus, its diffraction losses will be close to zero. Moreover, as a fundamental mode, we can choose a beam with the prescribed amplitude-phase distribution. For any other beam, diffraction losses will be significant. This laser resonator assures that, in a certain range of amplification gain factors of the active medium, (1) a single-mode laser radiation is generated and (2) energy accumulated within the active medium is efficiently converted into the fundamental laser mode.

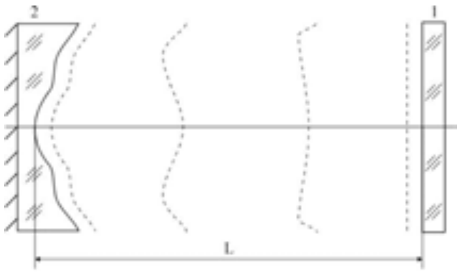

Fig. 7. Laser resonator designed for single mode laser operation. 1 – output mirror, 2 – rear mirror. Dashed lines show wave fronts of the beam corresponding to the fundamental transverse mode of the resonator [42]

Thus, separation by phases of fundamental modes makes it possible to overcome one of the major challenges of conventional resonators that use spherical mirrors and to effectively suppress the higher laser modes at a low level of diffraction losses for the fundamental mode.

4. Summary

This paper introduces a definition of the optical contradiction as a physical contradiction in which two opposite optical properties are required from the same component of the engineering system. A review of optical contradictions from geometric, wave, laser, and other areas of optics has been presented. It is shown that the wave nature of light allows us to use three special methods for resolving optical contradictions. These methods are (1) separation in the radiation spectrum, (2) separation by polarization, and (3) separation in phases of the light wave. We suppose that they can be a good in solving inventive problems in the field of optics.

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QUANTITATIVE APPROACH TO CAUSE-EFFECT CHAINS ANALYSIS

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Abstract

Cause-Effects Chains Analysis (CECA) uses qualitative approach for building causality diagram to model the analysed system, an approach similar to Root Cause Analysis (RCA) and Fault Tree Analysis (FTA) in several aspects. FTA, however, goes a step further by using the structure of the model and probability calculus to gain quantitative results reflecting reliability of the system. This paper proposes a quantitative approach and indicates some measures that could possibly enhance the CECA method.

This work was motivated by the need for supporting the selection of problems and solutions with business-oriented parameters, identified during previous research on transforming CECA diagram into Boolean functions, combined with author's experience in risk management area. Obtained results cover enhanced logical CECA model and formalized criteria for verifying its completeness, as well as a systematic approach to modelling of unequal importance of contributing causes and unequal profitability of candidate solutions.

Keywords: cause-effect analysis; Boolean logic; quantitative analysis; risk management.

1. Introduction

Concept of causality is used in various areas, including technology and business, for investigating the reasons and scenarios of past events (e.g. failures) as well as for anticipating future events (e.g. risks). Selected approaches to cause-effect analysis are described below, starting with the oldest ones and progressing towards those developed in TRIZ area.

Why-Why Analysis (also known as 5 Whys) originated at Toyota in 1930s and it is typically used for identifying improper on non-existent processes. The analysis starts with the observed problem and the question *why?* is repeated until the root cause is identified, with five iterations believed to be sufficient in most cases. This method is generally focused on process improvement, with the question actually meant *why did the process fail?* Known limitations include tendency to indicate a single root of a problem (while there may be several answers for each *why?*) and describing symptoms rather than actual root causes (because stop criteria are missing or inappropriate – such as the number of iterations). In spite of these drawbacks the Why-Why approach has been successfully blended into the TRIZ world by Pinyayev [1].

Root Cause Analysis (RCA) was developed by NASA in 1950s and due to its generic nature it is widely used nowadays in analysing systems and processes with respect to quality, safety, risk and other aspects. Its primary aim is to identify the root causes of harmful past events in order to determine actions or conditions that should be changed, added or removed to prevent the re-occurrence of similar harms in the future. The idea of improvement by learning from harms is close to 5 Whys and it is embedded into many of ISO documents addressing management systems.

These documents require organizations to identify causes of undesired events as a prerequisite for planning appropriate corrective or preventive actions. Comprehensive comparison of RCA and main TRIZ cause-effect analysis method was given by Abramov [2].

Fault Tree Analysis (FTA) was developed in Bell Laboratories in 1960s for the purpose of analysing failures in technical systems with qualitative (structural) and quantitative (probabilistic) model of causality [3, 4]. This method is traditionally used in aerospace, nuclear, chemical and other high-hazard industries for safety and reliability engineering and in IT industry for software debugging. It is a top-down approach starting with a failure condition and deducing how the system might fail that way, taking into account all possible causes. The outcome of the analysis is a tree-shaped diagram containing causes and logical operators (AND, OR) combining lower-level causes. Such model reflects possible variants of a system failure (root of the tree) that might be caused by particular combinations of initial conditions (leaves of the tree). Qualitative FTA ends with identifying minimal sets of conditions sufficient to trigger the failure. These sets are used for calculating estimates based on the probabilities assigned to respective causes and the nature of the interaction among the causes resulting from logical operators. The reliability of the whole system may be calculated then, by combining results from all branches.

Cause-Effects Chains Analysis (CECA) was developed in GEN3 in 1990s and it uses outcomes from other TRIZ tools: Function Analysis or Flow Analysis, for building diagrams of causality [5]. CECA starts by describing target disadvantages and investigates their causes until reaching a disadvantage that cannot be removed, which is usually a law of nature or a business constraint. The resulting graph consists of chains of disadvantages, possibly containing logical operators (AND, OR) or loops formed by cyclic paths of graph edges. Several enhancements have been proposed to the original concept in order to provide adaptive level of resolution, ability to discover hidden causes and support for automation in software using statistical regularities of disadvantage occurrence [6, 7]. The outcome of the analysis, i.e. key disadvantages and logical bonds among them, may be used for formulating problems that must be solved to eliminate target disadvantages.

Root Conflict Analysis (abbreviated as RCA+) was developed by Souchkov in 2000s [8] and it may be considered an extension of the CECA concept and graphical conventions. Contrary to CECA, which only deals with disadvantages, RCA+ investigates and documents negative as well as positive effects brought into the analysed system by particular causes, what in turn significantly expands the perception of the problem situation. Causes with both positive and negative effects represent conflicting requirements of removing and preserving given conditions. Thus the main added value of RCA+ with respect to CECA is a more complete model of causality with support for problem formulation, as the opportunities for inventive solutions may be easily identified. Interesting RCA+ extensions were proposed by Kisela [9], with quantitative measures aiding in selection of causes and use of fuzzy logic for developing model of causality in case of vague data.

2. The logic of CECA model

CECA diagram models causality with a directed graph containing disadvantages forming cause-effect chains and logical operators (AND, OR), indicating how the inputs affect the outputs. Therefore, only three generic variants can be modelled:

- given effect depends on one cause entirely, so that elimination of that particular cause would eliminate the effect,
- given effect appears if ALL the contributing causes appear jointly (logical AND), so that elimination of ANY of those causes is sufficient to eliminate the effect,
- given effect appears if ANY or several contributing causes appear (logical OR), so that elimination of ALL those causes is required to eliminate the effect.

A method of transforming a CECA diagram into set of logical functions was proposed in [10]. Root causes and target disadvantages were represented by binary variables with values of 1 / 0 reflecting active / inactive disadvantages, respectively. Logical operators were modelled as logical gates (AND, OR) with the appropriate numbers of inputs and each of the intermediate disadvantages was modelled as a repeater, i.e. single input gate repeating input state on its output. Since the repeaters do not affect transmitted signals, they were eventually removed and the final model comprised only input variables (root causes) affecting output variables (target disadvantages) through a network of AND / OR gates interconnected as in the original CECA diagram.

Such approach was sufficient to demonstrate how logical minimization, evaluation of sensitivity and other techniques using Boolean algebra might be used to support selection of disadvantages for removal by determining pertinent properties of the model. Nevertheless, applied simplifications resulted in a loss of information about intermediate disadvantages and in limiting the scope of interest to root causes only, which usually cannot be actually eliminated because of their nature. Building a more complete and more accurate model of logical relations in CECA diagram requires a different approach to intermediate disadvantages.

First of all, it should be noted that – counterintuitively – the relation between CECA cause and effect cannot be properly described using *logical implication*. In order to justify this statement we will use representation of Boolean functions with truth tables. AND gate outputs 1 only for 1s on all inputs while OR gate outputs 0 only for 0s on all inputs, and so the respective truth tables of 2-input gates are as follows:

AND

x	y	$x\,y$
0	*0*	*0*
0	*1*	*0*
1	*0*	*0*
1	*1*	*1*

OR

x	y	$x + y$
0	*0*	*0*
0	*1*	*1*
1	*0*	*1*
1	*1*	*1*

Logical implication is defined as *if x then y* and so it evaluates to 0 if and only if $x = 1$ and $y = 0$, i.e. true assumption must not lead to false thesis, which is equivalent to truth table given below.

implication

x	y	$x \Rightarrow y$
0	*0*	*1*
0	*1*	*1*
1	*0*	*0*
1	*1*	*1*

identity

x	y	$x \Leftrightarrow y$
0	*0*	*1*
0	*1*	*0*
1	*0*	*0*
1	*1*	*1*

We use 1 to indicate an active disadvantage, hence $x = 1$ models active cause (given disadvantage) and $y = 1$ models active effect (next disadvantage in the chain). Combinations $0 \Rightarrow 0$ and $1 \Rightarrow 1$ properly describe causality, but $0 \Rightarrow 1$ translates to an effect without a cause, what is unacceptable in the CECA paradigm and disqualifies implication as a logical representation of CECA causality.

Now, let us take a closer look at the single cause-effect pair, being basic element in the chain of causality. By drawing single arrow in the diagram from x to y, we actually *express our belief* that x and only x causes y (because, in general, we cannot be sure that no other cause or a combination of causes would not produce an identical effect). And by the way of using the diagram for planning changes in the system, we *express our belief* that elimination of x would definitely eliminate y.

For a single $x \rightarrow y$ link this relation looks as if y was repeating the value of x, what is equivalent to *logical identity* function described by the truth table presented above. However, for a chain of causes $x_1 \rightarrow x_2 \rightarrow \ldots x_N \rightarrow y$ we do assume that removing ANY of the cascaded causes would also definitely eliminate y. And thus we come to conflicting statements:

- given disadvantage in a linear chain depends entirely on the previous disadvantage, i. e. this disadvantage has only one control factor, explicitly indicated in CECA diagram, and
- given disadvantage in a linear chain may be eliminated without elimination of the previous disadvantage in the chain, i.e. at least one other control factor exists for that disadvantage, which is not indicated in CECA diagram.

This is equivalent to a physical contradiction describing properties of disadvantages in linear chains (with the exclusion of root causes):

- each disadvantage should have *exactly one control* to preserve coherence between the model and the diagram (as we only draw one arrow between the boxes), but
- each disadvantage should have *more than one control* to preserve coherence between the model and the concept (as we allow for removing the disadvantage without removing its predecessor).

As it was pointed out before, the requirement of removing ANY of the causes contributing to the output effect holds true for a coincidence of causes, implemented with AND operator. Therefore logical function modelling a chain of disadvantages should contain cascaded AND gates, with one input connected to the output of previous gate and the other input controlled by an independent variable, as shown in Fig. 1. First input is used for passing information about deeper causes in the chain and the second input controls given disadvantage directly. If any of the inputs is disabled (set to 0), the output is also disabled, simulating *indirect* and *direct* removal of the disadvantage.

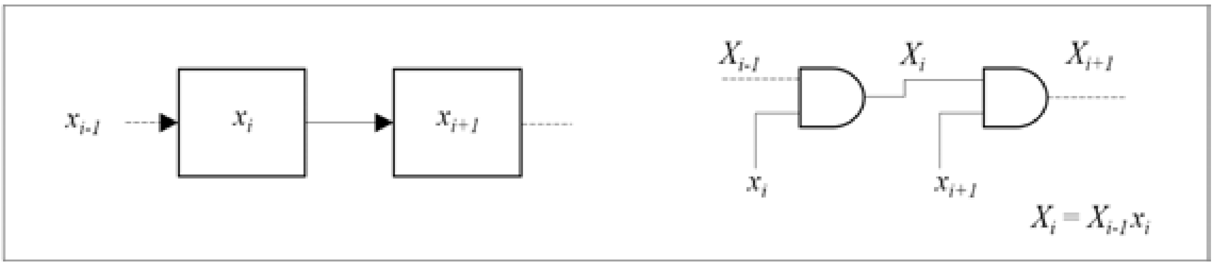

Fig. 1: Chain of AND gates modelling linear branch of CECA diagram

This approach to conversion of CECA diagram into a logical model offers several advantages with respect to the concept proposed in [10], but it introduces additional inputs controlling intermediate disadvantages, which have no counterparts in the diagram. On the other hand, CECA uses dual perception of intermediate disadvantages, which results in the contradiction indicated above. Using *separation in relation* principle [11] we split the status of the intermediate disadvantage between the input (independent of deeper causes) and the output (depending on deeper causes). One may also consider the incident cause as a *risk factor* and the local control as a *vulnerability* (weakness), so that a disadvantage is not observed if either the *risk factor in not present* (one or more of deeper causes are removed) or if the *vulnerability is eliminated*.

As it was suggested in [10], a representation of chained disadvantages in form of AND-ed logical variables is also appropriate for modelling simple loops (without branches) in CECA diagram. An additional benefit of proposed unified modelling comes from simple rules supporting in-depth verification of diagram completeness, which reflect recommendations 1.5.2 and 1.5.3 given in [5], translated into logical model domain (see details in Fig. 2):

- if one can indicate particular condition *causing* X_i irrespectively of x_i and X_{i-1}, then it should be modelled with a new control connected to an additional OR gate inserted into the chain at the output of x_i gate as and included in further analysis as e_i (enabling input),
- if one can indicate particular condition *preventing* X_i irrespectively of x_i and X_{i-1}, then it should be modelled with a new control (described as negated condition), connected to an additional AND gate inserted at the output of x_i gate and included in the analysis as d_i (disabling input).

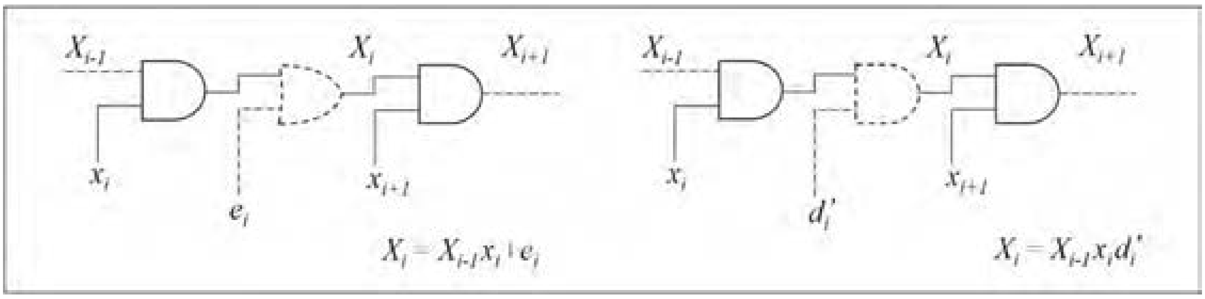

Fig. 2: Generic discovery patterns for verifying completeness of the logical model

3. Quantitative CECA extensions

3.1. Need for quantitative analysis

The logical model considered so far reflects the structure of causality, but tells nothing about the relative strength or importance of the factors affecting the system. For instance, parameters of electrical circuit may depend on the supply voltage and the operating temperature, and quantitative characteristics of these dependencies – e.g. calculated from the respective analytical formulas – would allow for better decisions regarding changes in the system. And even in case of identical analytical description of two causes, their actual impact on the system may be quite different, especially if they are known to appear with different intensity or frequency. Extending CECA approach to make use of such parameters for supporting selection of disadvantages with the biggest influence on outcomes would probably allow for better allocation of the efforts.

In addition to being technically feasible and properly addressed, the changes in the system are also expected to be beneficial with respect to its purpose, usually defined at the super-system level. Therefore appropriate business criteria should be taken into account while assessing candidate changes. Apart from typical financial measures, such as costs and revenues, there are several other parameters that might be crucial, like timespan or compliance. And even if they cannot be directly compared with other measures in apples-to-apples manner, they still may (and supposedly should) influence the decisions. The following sections address quantitative measures that could possibly enhance CECA method by asking:

- How strongly particular cause influences the effect, compared to other participating causes?
- How much money (or other resources) is required to eliminate particular disadvantage?
- How much money (or other resources) is expected if particular disadvantage is eliminated?

And before addressing these topics, we will briefly recall basic concepts of various measurement scales, as described by Hubbard in [12]. **Nominal scale** uses categorization into distinct classes and scale labels have no explicit order (e.g. names of countries). The only allowable relation is identity (or set membership), so that a value falls either inside or outside the particular category. **Ordinal scale** defines the rank order, but the distance between values has no interpretation (e.g. education levels). In addition to identity some order relation also apply, such as greater or lesser. **Ratio scale** is an ordered scale that allows for interpreting the difference and the ratio of values (e.g. speed). Values on such scale may be directly compared, added, subtracted and divided and this is the type of scale which we are probably most familiar with. **Interval scale**, not mentioned in [12], is an ordered scale, where the difference of values does have interpretation, but the ratio of values does not (e.g. Celsius temperature).

Measurement is defined in [12] as: *quantitatively expressed reduction of uncertainty based on one or more observations*, while [13] defines **risk** as: *effect of uncertainty on objectives*. Indeed, we want to support decisions with data (from actual measurements or estimations), which decrease the uncertainty and thus reduces the risk of improper understanding of the problem situation.

3.2. Modelling unequal impact of contributing causes

CECA diagram is considered complete if no other causes can be identified by the team members performing the analysis, what does not guarantee in any way that such causes do not really exist. The whole process is based on judgements and beliefs coming from knowledge and experience of the team, possibly supported by external consultants or dedicated software. Considering the above-mentioned risk definition, such situation might be perceived as neglecting (and accepting) the risk of influence on the target disadvantages coming from unknown causes. And if those causes are presumed not worth further research, then *some ordinal scale must have been used* in the process to decide that particular causes are less important than others. It may be argued, therefore, that in spite of its generally qualitative nature, the original CECA approach uses implicit quantitative criteria.

Different nature or different importance of the causes may be reflected in the model in a few ways. Categorization (nominal scale) can be used for labelling or tagging disadvantages accordingly to their characteristics (e.g. internal vs. external, materials vs. procedures and so on). Tags may also indicate perceived rank of the problems (small vs. big, simple vs. complicated etc.), thus defining an ordinal scale. Priorities or, better yet, numeric weights of causes (ratio scale) may also be deduced from the order of interaction – for instance electrical resistance contributes to the heat dissipation in a linear fashion, while the influence of the current intensity is quadratic ($P \approx I^2R$). For repeatable causes, historical maintenance data may be used to estimate empirical probability of manifestation of disadvantages.

3.3. Modelling unequal profitability of candidate changes

In order to evaluate profitability of candidate changes in the system, we need to estimate the benefits and investments for each of the considered disadvantages. In the case of system redesign the benefits may come from additional revenues or from avoided losses. Preferably, they should be given as monetary values, or values in other ratio scale (e.g. workload expressed in man-days). But in fact we are more concerned with the question *which one?* than *how much?* And therefore an ordinal or interval scale may be applied, as they are both suitable for ranking (e.g. this quarter vs. next quarter). Even nominal scales may be used, if specific categorization enhances decision-making process (e.g. short-term vs. long-term, in-house vs. outsourced etc.). Similar categorizations are used for supporting business decisions (such as four importance / urgency quadrants) and they may also address quality, security, or compliance topics (e.g. mandatory vs. optional or must have vs. want to have vs. nice to have).

The concept of evaluating profitability of the candidate changes is in fact analogous to assessing ideality of a system using benefits, costs and harms: we want to maximize measure of advantages and minimize measure of disadvantages. This is also similar to systematic dealing with risk: if we know how much and how likely the loss may be and how much would it cost to reduce the loss, then we may quantitatively evaluate risk handling options and decide if we choose to invest in mitigation or perhaps we prefer to accept possible consequences of risk materialization.

3.4. Merging logical model with quantitative description

As stated in section 2, for AND condition it is sufficient to eliminate ANY of the contributing causes. The logical model proposed in [10] offers algorithmic way of evaluating the influence of particular inputs (key disadvantages) on outputs (target disadvantages) for selecting the causes with the greatest impact, but still the impact is calculated solely from structure (i.e. influences of all the inputs are presumed to be equal). With quantitative parametrization we are able to choose the most profitable option systematically. Moreover, the selection criteria may be adjusted for a specific situation, to indicate the cheapest solutions (in terms of implementation investments), the easiest solution (in terms of uncertainty), the fastest solution (in terms of time to market), etc.

For OR condition, it was stated that ALL contributing causes should be eliminated to remove the target disadvantage, so it looks like there is nothing to gain here with quantitative approach. But actually we don't have to struggle for the total elimination of a disadvantage if the reduction of its harmful outcomes is an acceptable solution [5]. Observations in many technical and social areas show that majority of effects come from small subset of causes, which is known as *Pareto rule* or *80/20 rule*. Therefore it does make sense to begin the elimination process with causes being more impactful or more frequent than others. The quantitative CECA model directly supports such selection and it also allows for estimating the improvement (increased ideality) of the system.

4. CECA and risk management

Risk management paradigm appears to be especially suitable for supporting quantitative CECA:

- it allows for expressing the results in business metrics, understandable for decision makers,
- it corresponds with the concept of direct and indirect elimination of disadvantages,
- it is already used (implicitly) in the original process of building CECA model.

The recommended approach to risk evaluation [13] combines the likelihood and consequences of an event to determine the risk magnitude. This may employ simple ordinal scales for probability and impact (e.g. low / medium / high) indexing a "risk map" table with risk magnitude predefined for each probability-impact combination (e.g. negligible / low / medium / high / critical). The risk magnitude may also be evaluated numerically by multiplying measures of probability and impact, while some methods use measure of vulnerability in multiplication as well:

$$\textit{risk magnitude} = \textit{probability} \bullet \textit{vulnerability} \bullet \textit{impact}$$

If appropriate scales are used, the risk magnitude may reflect the estimated loss expressed by the amount of money (just like in forecasting sales revenues from a contract value and probability of success). A ranking list of such results allows for identification of the most important items.

Further steps of risk management process are usually described as: *deciding on strategy* (tolerate, terminate, transfer or treat), *dealing with risk* (i.e. implementing selected strategy) and *monitoring effectiveness* of risk mitigation. In practice, there may be several mitigation activities considered for same risk factor, possibly leading to different results. Therefore proper selection of activities should take into account the residual risk magnitude, calculated from forecasted probability and impact (and perhaps vulnerability) after mitigation, as well as estimated mitigation cost. The ratio of difference between the initial and residual risk magnitude and the required investment indicates how much profitable (or justified) is particular mitigation option.

$$\textit{profitability} = (\textit{initial risk magnitude} - \textit{residual risk magnitude}) / (\textit{cost of mitigation})$$

Risk factors are similar to disadvantages and mitigation options are similar to candidate solutions, so that decision support procedure used for risk management seems to be directly usable for providing quantitative extensions to traditional CECA method, as indicated in the following lists.

Risk management

1. identify risk factors,
2. estimate initial risk magnitude,
3. select risks from prioritized results,
4. analyse risk mitigation options,
5. estimate residual risk magnitude,
6. estimate risk mitigation costs,
7. calculate profitability of mitigation options,
8. select mitigation options.

Quantitative CECA

1. identify disadvantages (regular CECA ends here),
2. estimate initial impact of disadvantages,
3. select disadvantages from prioritized results,
4. analyse solution options,
5. estimate residual impact of disadvantages,
6. estimate disadvantage removal costs,
7. calculate profitability of solution options,
8. select solution options.

The first part of the procedure (steps 1-3) only requires information about influence of particular causes and it results in a list of key disadvantages (and, possibly, intermediate disadvantages) ranked by their impact on the target disadvantages. The second part (steps 4-8) offers support for selection of candidate solutions, but it requires quantitative estimates concerning those solutions.

5. Example

To illustrate main ideas described above, we will use a simple example regarding construction of a cargo UAV (Unmanned Aerial Vehicle). One of the identified target disadvantages is excessive UAV impact in case of an emergency landing and part of the respective CECA diagram is given in Fig. 3, revealing a tree-like structure with 2 intermediate disadvantages and 4 key disadvantages.

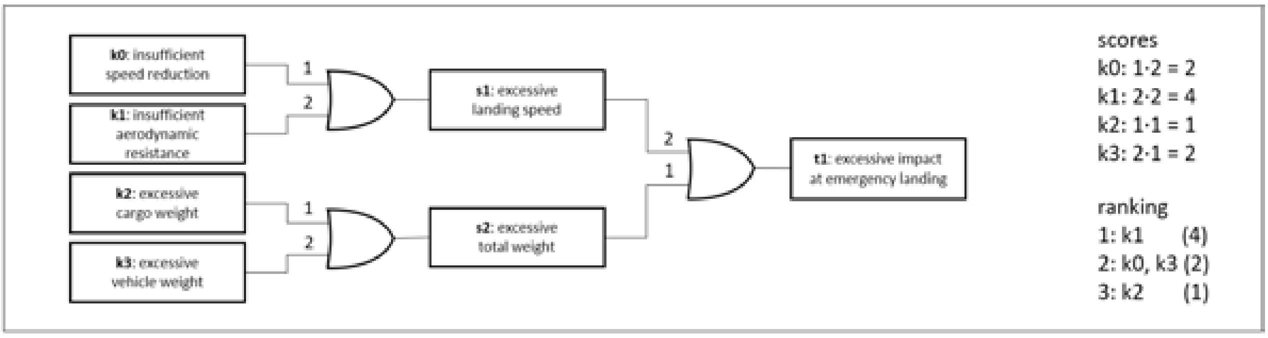

Fig. 3: Fragment of CECA diagram developed for cargo UAV with ranks and scores

Let us analyse the situation quantitatively, in order to differentiate the branches of the graph:

- Kinetic energy of the impact is proportional to the mass and squared velocity ($E \approx mv^2$), hence velocity of the moving vehicle influences the impact more strongly than its mass does.
- The mass of a loaded vehicle depends on the mass of the vehicle itself and the mass of the load. Decreasing the load would contradict with the main function of a cargo UAV. Therefore, decreasing the mass of the UAV is the preferred solution search option.
- Speed reduction requires many components to be operational (power source, control,

motors, propellers, etc.) and this conditions may not hold true during an emergency landing. Therefore, increasing aerodynamic resistance of the UAV is the preferred solution search option.

These preferences are annotated in the diagram (higher rank denotes higher importance or priority) and the scores for particular causes are calculated by multiplying coefficients along the path to the target disadvantage, as shown in Fig. 3.

We don't know any candidate solution, but we do know our competences and the equipment, and so we are able to rank the areas for investigation from the most preferred (internal experts with appropriate tools) to the most risky (external experts or additional tools required). This seems to be a realistic and relatively common situation. Let us assume, that the priorities are as follows:

4 – embedded UAV software and on-board electronics (sensors, interfaces, etc.),
3 – mechanical construction of the UAV (body, arms, legs),
2 – mechanical construction of the cargo module,
1 – power supply (battery, power management and harvesting) and drive (motors, propellers, etc.).

Multiplication of the previously calculated scores by priorities assigned to respective areas of the expected solutions produces the following results:

k0 (drive train)	$2 \cdot 1 = 2$
k1 (UAV construction)	$4 \cdot 3 = 12$
k2 (cargo module)	$1 \cdot 2 = 2$
k3 (UAV construction)	$2 \cdot 3 = 6$

Again, k1 has been assigned the highest score and k3 appears to be more preferred than k0 and k2.

As can be seen, additional knowledge about the system and its context may be easily expressed in quantitative form and used for supporting selection of disadvantages. It is a heuristic technique, as we might use other ranks or other calculation schemes (e.g. addition instead of multiplication). Nevertheless, such approach seems more useful than scanning all of the disadvantages one by one.

6. Summary

This paper analyses logical relations in CECA diagram and introduces significant enhancements to the previously proposed method of modelling such a diagram with a set of Boolean functions [10]:

- retaining all intermediate disadvantages in the logical model,
- providing controls for modelling direct removal of intermediate disadvantages,
- allowing for unified modelling of linear chains and simple loops in the graph,
- introducing formalized criteria for verification of model completeness.

Analogies between logical CECA model and the key concepts from the risk management area have also been identified and explored towards quantitative CECA extensions by:

- supporting quantitative cause-effect analysis idea with appropriate measurement scales,
- indicating approach and sample parameters for modelling importance of disadvantages,

- indicating approach and sample parameters for modelling profitability of candidate solutions,
- indicating approach for merging quantitative descriptions with logical AND / OR conditions,
- adapting risk management procedure to support decisions on changes using CECA model.

The proposed quantitative approach was inspired by development of the risk assessment process and tools being used by Pentacomp within its certified Information Security Management System (ISMS). We express risk impact, risk magnitude and estimated costs as money amounts and we use non-linear scales of probability and consequences, which simplify evaluation. We have also implemented automated recommendations using parametrized risk appetite and a profitability measure to advise the user whether a given risk should be accepted, mitigated with pre-evaluated activity or analysed further. All these features also seem applicable in supporting decisions on changes in technical systems modelled with CECA.

7. Conclusions and further work

The main research outcome regarding logical model is the enhanced and unified representation of CECA chains, resulting from the solved contradiction describing direct and indirect elimination of intermediate disadvantages. The identified analogy between the direct removal of disadvantages and vulnerabilities of the system revealed risk management as an appropriate and advisable vehicle for extending CECA with quantitative analysis, which may be based on various scales (also non-numerical). And, as in the risk management area, we are primarily interested in using the quantitative model and calculations to support the selection of items, i.e. proper ranking of the results is more important than exact scores.

Described concepts have not been tested in real-life cases yet, so that verification of usability of the method appears to be the first item on the to-do list. This applies to the unified logical CECA model as well as quantitative CECA extensions. The latter seems especially challenging and the quotation from the book *How to Measure Anything* [12] will hopefully aid in approaching this task:

"Four Useful Measurement Assumptions

1. *Your problem is not as unique as you think.*
2. *You have more data than you think.*
3. *You need less data than you think.*
4. *An adequate amount of new data is more accessible than you think."*

Another topic for further work is related to the criterion proposed for verifying completeness of the model. It addresses search for a factor capable of removing given intermediate disadvantage, irrespectively of deeper causes. To update the logical model, we should use negated description of that factor (e.g. *broken insulation*). However, in direct form (e.g. *intact insulation*), the condition would be actually a draft, or at least an inspiration, of a strong solution. Hence the idea of using vulnerability patching analogy in the process of problem formulation and selection seems to be worthy of additional research.

Acknowledgments

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REPORT ON THE 2ND EUROPEAN REMOTE TRIZ WORKSHOP

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Abstract

On January 20th 2017, the 2nd European Remote TRIZ Workshop took place. Organized by Robert Adunka in his capacity as European Vice President of MATRIZ, the one-day workshop challenges groups of TRIZ practitioners from a wide range of backgrounds and companies with a common problem. Each group independently works on the problem and gives a short summary of their approach and results at the end of the day.

In the following the challenges faced in setting up the workshop are explored, the experiences throughout the day are explained, and the learnings summarized.

Keywords: TRIZ, Workshop, Remote, Case Study.

1. Introduction and Workshop

January 20th in the year of 2017 was a cold winter day in most of Europe. But this could not deter ten groups of engineers and students from four different European countries to spend a day virtually together to work on a single problem, one that is increasingly affecting the world. Some of the participants work in different companies that, in some fields of business, are fierce competitors. Others were students either in their secondary education or in their university studies. What brought this diverse group together, and why would they be willing to share their knowledge and skills?

The answer of course is TRIZ, the Theory of Inventive Problem Solving [1]. For the second year running the European branch of MATRIZ organized the European Remote Workshop. This workshop brings together participants from the TRIZ community all over Europe for a day, to work together on a single problem. The following table shows the overall agenda of the day.

Table 1

The agenda of the day

A few days in advance	Sent the problem description to all participants
09:00 – 10:00	Briefing on the Problem

10:00 – 15:00	Work on the problem
15:00 – 17:00	Debriefing, 10 minutes per group

The formula used is, in principle, easy:

1. In preparatory sessions a problem is selected that is wide enough for everyone to be interesting to work on.

2. In a morning session, lasting a maximum of one hour, the problem is explained to all participating groups via internet communication means. This enables the exchange of spoken word but also of drawings, sketches and the like. At this point participants can ask questions for clarification.

3. For the rest of the day, until 3pm, participants work on the problem in their respective groups, using a variety of TRIZ and supporting tools to frame, analyse and solve the given problem. By 3pm the groups should have uploaded a small presentation file onto a common SharePoint.

4. From 3pm onwards each group successively presents both the approach they used as well as a summary of the resulting ideas. Other groups may ask questions for clarification.

Of the ten participating groups the three groups from France were Engineering Students from ECAM Strasbourg-Europe, Innovation & IP specialty [2] and Marketing & Communication students from ISEG MCS Strasbourg [3]. Furthermore, one of the groups from the Netherlands was from secondary education. Figure 1 gives an overview of the groups that participated in the workshop:

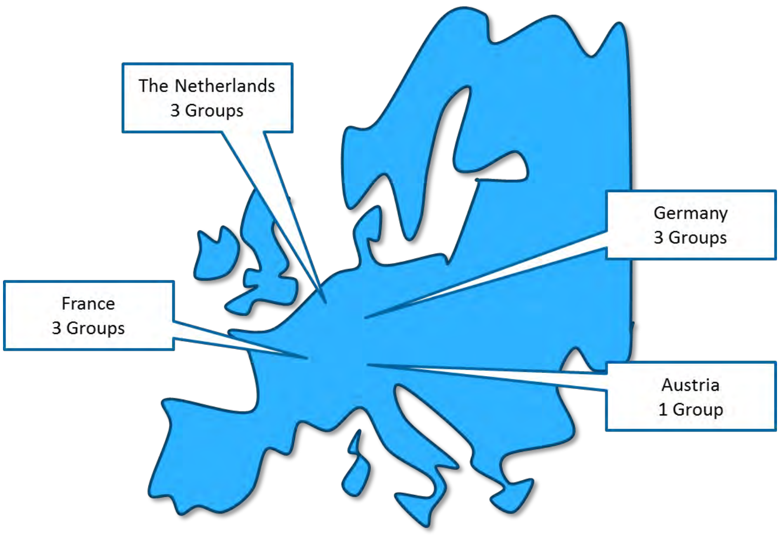

Fig. 1. An overview of the groups that participated in the workshop

Overall the workshop was intended to be a platform for the participants to learn from each other, in the groups and across the groups, to compare different approaches and results, and to build a stronger Europe-wide network of TRIZ experts.

Choosing a problem proved difficult for a number of reasons. As a number of multinational companies participated, the topic had to be in a non-competitive field. And as economic and marketing students were involved, the problem could not be too technical either. After some toing and froing the problem chosen was:

> Today global water withdrawals have reached 3,903 km^3/per year and have been outpacing population growth by a factor of 2 over the last two decades. This increase in utilization has been driven by population growth, increased wealth, industrial development and agriculture…We can then infer that overall global demand and potential shortages will continue to increase as nations continue to industrialize…Each team should select a an area of interest and develop ideas to solve the problem of water scarcity

2. The Learnings

To evaluate if the workshop purpose was achieved, a few days after the event a Questionnaire was sent to all participating groups, and at least one answer was received from each professional group. No feedback was received from the student groups. The purpose of the questionnaire was to gather information on how the participants experienced the workshop and to identify possible improvement opportunities for future workshops.

The questionnaire was kept simple to enable a quick response. Apart from asking for some details of the respondent, the questionnaire consisted of the following six questions:

1. On a scale of 0 – 10, how likely are you to recommend this workshop to a (TRIZ-minded) colleague or friend?
2. In your view, what is the most unique feature of the workshop?
3. What are your key learnings / takeaways from the workshop?
4. In your view, what are the key success factors for the workshop?
5. What would you improve?
6. Any other comments you may have:

Responses were received only from the six professional groups, and therefore the results do not reflect the input from the student groups. The 12 responses represent 55% of the participants from the professional groups.

The respondents were quite well trained in TRIZ; most participants had followed a MATRIZ Level 2 training or higher.

2.1 Q 1, how likely are you to recommend this workshop?

Question number one, is also known as the Net Promotor Score [4]. The theory behind the question is that people who have experienced the service, product or offer can be classified either as Promotors (those who score a 9 or 10 and are highly likely to tell their friends about their good experience), Passive (those who score a 7 or 8 and who will neither praise nor condemn the experience) or Detractors (those who score a 6 or lower and who are likely tell about not so good aspects of their experience). A score is calculated by subtracting the number of Detractors from the number of Promotors and, ignoring the Passives, dividing the resulting number by the total amount of respondents and expressed in %. As a general guideline, for a good result the resulting score should be above 0%.

With one respondent giving an ambiguous response which was subsequently discarded, the resulting score from the questionnaire is 18% which indicates that the workshop was reasonably well received. In the responses all three, Promotors, Passives and Detractors were represented.

The Detractors reasoned that, given the open nature of the problem given, too much time had to be spent on analysis rather than on problem solving, leading to superficial problem solving.

2.2 Q 2, what is the most unique feature of the workshop?

Most respondents mentioned aspects like learning, working together, comparing results and sharing ideas, methods and theory. This fits in perfectly with the goal set for the workshop to share and learn from each other. A few participants also felt strongly about being able to solve a problem in a way that can bring real improvement to the world, which reflects on the problem given.

2.3 Q 3, what are your key learnings / takeaways from the workshop?

About one third of the answers highlighted the importance of teamwork the widening of one's horizon and seeing the different approaches of the teams as important. One participant felt this was easiest done in areas that are easily accessible to all participants, and that also are easy to realize. Most participants furthermore mentioned the importance of understanding and analysing the problem, and the time that has to be taken to do this well.

A number of answers highlighted the importance of the problem statement. It was felt that the problem definition strongly affected the results and that a broad problem – as used – could confuse participants and required a lot of time for initial research. It was felt that the TRIZ analytical tools really helped here [5]. One answer extended this to the overall organization of such a remote workshop. In that light the format would need adaptation to be really successful as attempts to solve a very broad problem in a short time invites superficial approaches. One respondent had as a key learning that classical tools as paper, cardboard and handwriting is much faster in idea generation, but less good for documentation in comparison to digital media. The importance of graphical representations to improve the communication of ideas was also highlighted.

2.4 Q 4, what are the key success factors for the workshop?

Many answers clearly stated the importance for the ability to and time for sharing the approach and results. Reflecting a problem on the day, in this context a well-functioning conference system was deemed worthwhile to be mentioned. As a second important success factor it was mentioned that the clear definition of a neutral, important and motivating problem is crucial. Organizational such a workshop has to be well prepared with pre-information about the agenda and content. Other comments were concerned with the importance of having trained people present and the use of problem analysis.

2.5 Q 5/6, what would you improve? Any other comments you may have.

Many responses mentioned the problem of the day; both, the difficulty in identifying a problem that is suitable for all participants, as well as the (lack of) specificity of the problem was commented upon. Potentially adding additional information to ease the research phase was recommended. It was generally felt that the generic nature of the problem given asked for too much time for analysis. Either giving more time for that phase or splitting things up into more and shorter workshops were two suggestions to overcome this problem. Two respondents felt that the conference system / internet connectivity could be improved upon. The idea of evaluating the workshop with a questionnaire was positively seen, and furthermore the wish was expressed to somehow be able to use the resulting ideas.

2.6 Response from the student groups

No questionnaires were returned by the student groups. However, from discussions several points became clear and are mentioned in the following:

The knowledge of TRIZ tools of the students was more limited than with the professional groups. It ranged from a 2-hour introduction to TRIZ which was conducted by one of their peers to about 40 hours of TRIZ and IP training conducted during 4 months. A more intense TRIZ training definitely helped during the project, both in the analysis phase as well as in problem solving.

The student groups and their mentors reacted very positively on the format of the workshop, and most would participate in a similar event again.

Three groups of students could not participate in the event in real-time, due mainly to internet connectivity issues, but they still experienced the event as valuable.

2.7 Guideline

Based on the experiences learned from running this workshop for two times, and from the feedback received from all participants a guideline to setting up such a workshop has been created. Table 2 contains the main elements a potential organizer would have to take into account for a basic setup:

Table 2

Guidelines for setting up a remote TRIZ workshop

#	*What*	*Who is responsible*	*Duration*
Before the workshop			
1	Determine the organizer	**All interested parties**	-
2	Determine the participants, how many groups and which groups.	**Organizer** (groups)	-
3	Determine the main stakeholders (group leaders / teachers)	**All interested parties**	-
4	Set date for the workshop	**Organizer** (stakeholders)	-
5	Set date for evaluation	**Organizer** (stakeholders)	-
6	Plan rooms for the groups	**Organizer** (stakeholders)	-
7	Determine the problem to be tackled in the workshop	**All interested parties**	1h – 4h
8	Prepare the Analysis for the workshop and prepare agenda	**Organizer** (selected stakeholders)	4h
9	Define the communication medium	**Organizer** (stakeholders)	-
10	If telecommunication media (skype) is used, set a date for a test-run	**Organizer** (stakeholders)	-

11	If telecommunication media (skype) is used, prepare a shared drive and communicate to all groups	**Organizer** (stakeholders)	-
12	Dump Problem, Analysis and Agenda on shared drive	**Organizer** (stakeholders)	-
13	Test-run telecommunication medium	**All interested parties**	1h
On the day of the workshop			
1	Log in / walk in	**All interested parties**	½h
2	Present Problem, Q/A	**Organizer**	1h
3	Work on problem	**All interested parties**	5h
4	Feedback to other groups	**All interested parties**	1h – 2h
After the workshop			
1	Evaluate	**All interested parties**	1h

3. Conclusions and Questions

Despite the cold and dark January day, the participants of the workshop experienced the day overwhelmingly as very positive. The opportunity to learn from each other, both in the groups but also across the groups and to practice TRIZ tools on a neutral project were very well received.

Choosing a more concise problem and possibly preparing the general analysis around that problem in advance was generally felt would increase the learning aspects of using TRIZ problem solving tools. Internet connectivity should be improved as some groups experienced severe problems here.

The general format proved robust, successful and fun. It may be worthwhile exploring further. It could, for example be used in University contexts, with different student groups working in parallel. Or different groups could use different tools to investigate the same problem. These alternative ways of working are the topic of further research.

Acknowledgements

The author would like to thank Dr. R. Adunka who was the mastermind in the background, Mr. M. Lynas and Ms Tiziana Bertoncelli from GE who with their colleagues co-authored the problem and provided the internet connectivity. Special thanks also to Pascal Sire and Roland Waldner for their post-event discussions. A final thanks to all participants for helping to shape a memorable day full of TRIZ experience.

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RESEARCH ON TRIZ INTEGRATED FBS-A REPRESENTATION

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Abstract

The knowledge of TRIZ is abstract, which brings difficulties to solve specific problems in professional fields. In order to deal with this matter, combined Function-Behavior-Structure representation with Affordance representation, a solving process integrating FBS-A representation with TRIZ is put forward. Based on situated analogy, FBS-A is used to guide the cognitive process and realize the analogy process from source of analogy to target design. Integrated the knowledge base, the effects base, the analytical and solving tools of TRIZ, the U-FES model driving technical system evolution is constructed. The solving process supports function solving and technical system to be improved, which can not only be applied to the innovation of behavior and structure in the target design but also the diagnosis of function unit solutions during analogy. An illustrative industry application demonstrates that the method is feasible, where the evolution of process layout about the multi-type vehicle production line in an automobile company is presented.

Keywords：TRIZ；FBS；Affordance；UXD

1. Introduction

In terms of technology forecasting, function solving, contradiction solving, substance-field model solving, together with the knowledge base and effects base contained, TRIZ has provided powerful support for innovative design. However, the problems unresolved as follows still remain obstacles to analysis and solution using TRIZ efficiently:

(1) Design problems should be transformed to the form of TRIZ, that is contradiction, substance-field model, function vocabulary, etc. (2) The knowledge representation of TRIZ is abstract, which leads to abstractness and generalization of the solutions of TRIZ. (3) Function verbs of TRIZ are too specific to support the function decomposition. (4)The knowledge models currently are incapable of integrating multiple solving tools, even though the ARIZ algorithm is also limited in the framework of TRIZ theory.

Therefore, to support the analysis and solution of TRIZ, integrating other design theories and technical methods into TRIZ becomes a research hotspot. At present, there have been a variety of methods in this aspect, such as QFD/TRIZ[1], AD/TRIZ[2], 6sigma/TRIZ[3], AFD/TRIZ [4], FMEA/TRIZ[5] ,etc.

The study combines Function-Behaviour-Structure (FBS) representation with Affordance (A) representation and proposes a solving process integrating FBS-A representation into TRIZ. The method is demonstrated feasibly through an illustrative industry application where the evolution of process layout about the multi-type vehicle production line in an automobile company is presented.

2. Main methods

2.1 Situated analogy process based on FBS-A representation

Affordance (A) representation is defined as the process based on Affordance [6] that conveys the cognitive contents of the relationship between technical system and environment in situated analogy, by which the analogy of affordance between source of analogy and target design can be supported in representation. A representation combined with FBS[7] representation, that is describing the driving knowledge of evolution process by function, behavior, structure and affordance, builds FBS-A representation. Wiggins[8] defines unexpected discoveries (UXD) as the emergent features that haven't been predicted previously by designers but emerge during the situated design. The key to realizing the situated analogy is to extract UXD during building memories. FBS-A has been used in the study to support the UXD process in the situated design. The process is shown in Fig.1.

The UXD process based on FBS can support the innovation of function, behavior and structure in the target design. Analysing the UXD obtained by A can find out the relationships between technical system and environment which have adverse effects on the expectation of system. A can complement FBS in that it can find out UXDs from additional features that become fuzzy gradually in the situated analogy driven by FBS. The functions and effects database of TRIZ can be used to solve problems in FBS model. The tools of contradiction and substance-field model solving in TRIZ, together with 76 standard solutions and 40 inventive principles, can provide solving strategies for the A model.

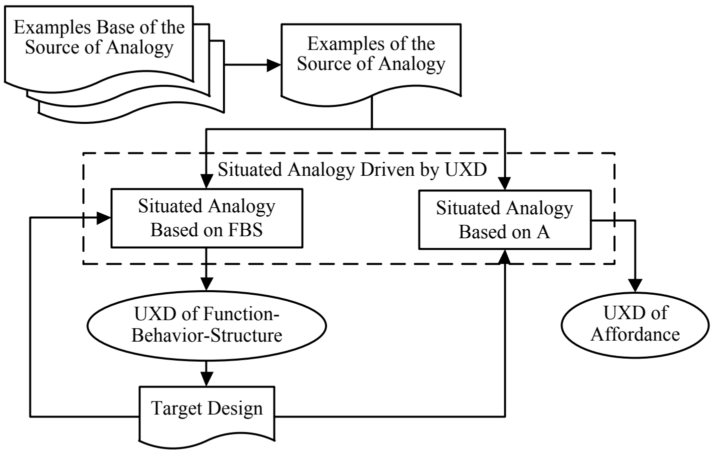

Fig. 1.The Situated Design Process Based on FBS-A Representation

2.2 U-FES model based on FBS-A representation

Aiming at the abstractness of the knowledge base and the effects base in TRIZ, based on the situated design, target design is supported by analogy, in which the effect examples of TRIZ are used as sources of analogy. The study builds unexpected discovery function effect structure model (U-FES), as is shown in Fig.2, which is a solving process of situated innovation driven by UXD and supported by FBS-A. The process includes the description of design task, the definition of function structure, the mapping from function unit to effects, the production of principle solution from effect examples, the innovation of technical system driven by UXD based on FBS-A, filing, etc.

In the model, before the conceptual solution to target design coming out, the cognitive process of situated analogy is driven by FBS. After the conceptual solution to target design coming out, the cognitive process is driven by FBS and A simultaneously. In this stage, FBS can drive the innovation process of target design by UXDs extracted from behavior and structure in the case of function matching. While in the case of Function-Behavior-Structure matching, A can drive the innovation process of target design by UXDs extracted from affordance. If extracted, UXDs can be defined as contradictions of TRIZ and solved by solving tools of TRIZ, which can propose new solving targets to target design.

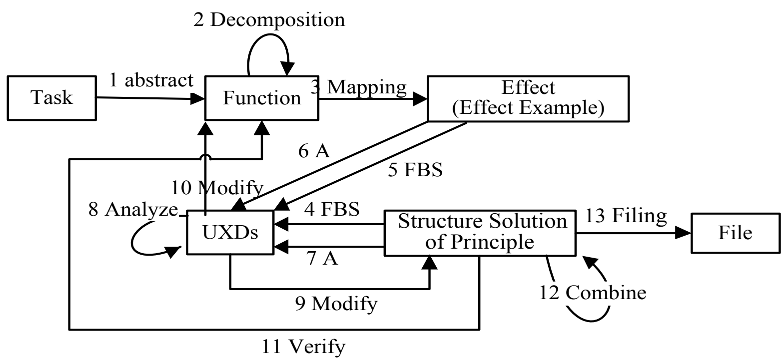

Fig. 2. The Process of U-FES

The process has the following advantages:

1. Effects base of TRIZ has been utilized fully to realize function solving. Owing to build the mapping relationship of key knowledge by analogy and make full use of knowledge resources in TRIZ, the process need not develop the knowledge base of behaviour and structure or the mapping relationship between them.

2. The affordance relationship of effect examples can provide auxiliary support for the diagnosis in the affordance relationship of target design.

2.3 Framework of Solving Process Based on U-FES

The framework of solving process based on U-FES describes how the structure solution of principle comes into being from requirement analysis, as well as the interwoven application of the knowledge base, the function &effects base, analysis and solving tools of TRIZ in the design process (see Fig.3). In the figure, the shaded parts are key technologies to realizing U-FES. Due to space limitations, a brief introduction is made here.

1. The implementation technology of solving framework is divided into two stages: the function- effect examples stage and the effect examples-function unit solutions stage. The function-effect examples stage is a process that decomposes total function into function units and then searches effect examples for function units. Using two grade mapping relationships, that is the function-effect examples and the effect examples- function unit solution, the study rebuilds and extends the function & effects base of TRIZ based on the function ontology and simultaneously builds the structure of knowledge and the knowledge management methods at different levels

in the model, all of which can support to realize the first stage. The second stage is also supported by the knowledge base, the function &effects base, analysis and solving tools of TRIZ.

2. FBS-A is built by combining A with FBS, which has been expounded detailedly in section 2.1 and 2.2.

3. The process of UXD is determined jointly by the source of analogy examples, the analogy target and the knowledge of designers; moreover, the effect examples searched by the search module of effect examples may be various. Those have great significance for motivating designers to make full use of their knowledge in the innovation process.

4. The analysis and solution module of TRIZ can transform negative affordances obtained by the affordance analysis to the contradiction or substance-field model of TRIZ. The problem solving tools of TRIZ include the knowledge base, the effects base and the tools of function solving, contradiction solving and substance-field model, etc.

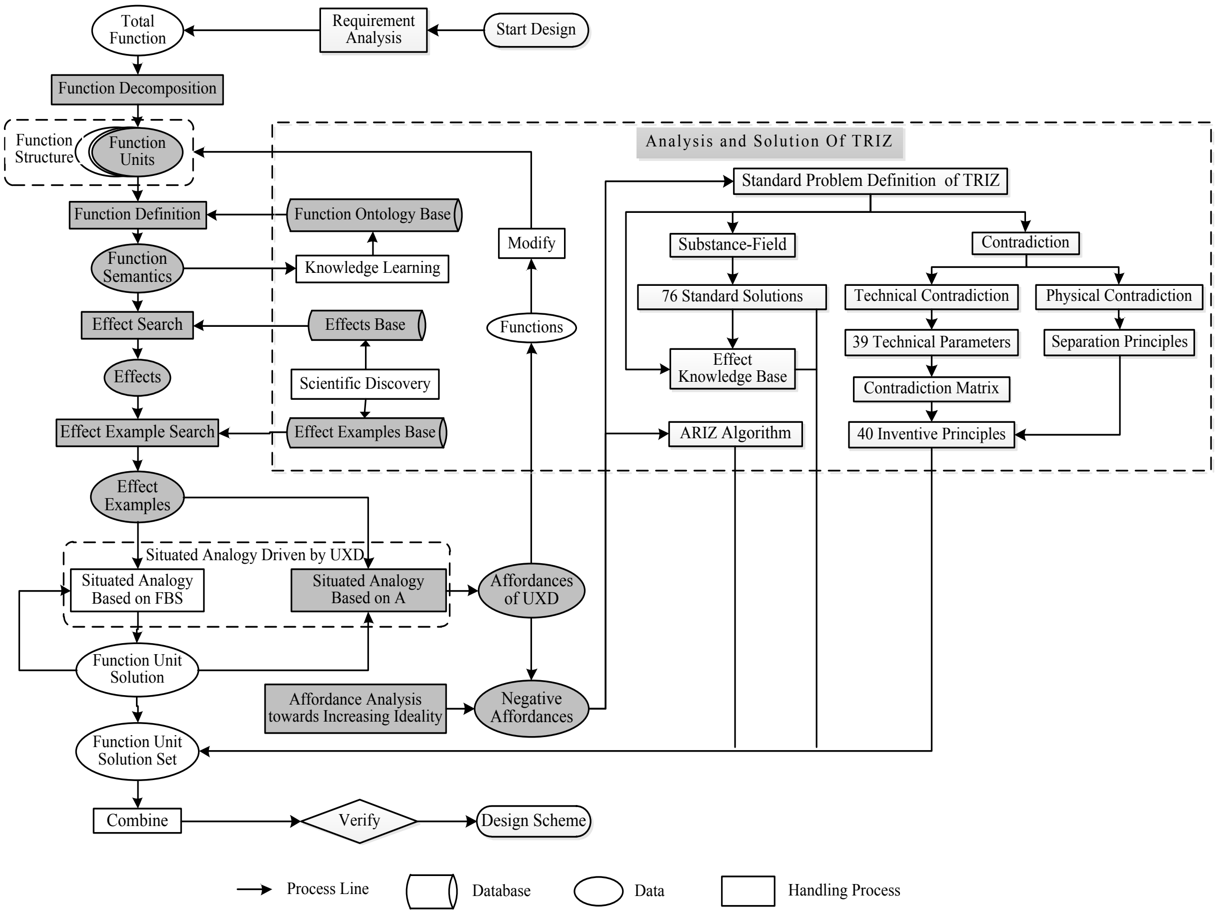

Fig.3. The Framework of Solving Process Based on U-FES

3.Application examples

The paper takes the multi-type vehicles common production mode of the Fitting Line in the Body Shop of an automobile company as an example, in which the solving process integrating FBS-A with TRIZ has been applied and the problems generated in the production process have been analyzed and solved successfully. The proposal has already been put into practice.

3.1 Project overview and description of the problem

The work tasks of the Body Shop's Fitting Line is to assemble and adjust Front Doors (FD), Rear Door (RD), Engine Hood (HD), Deck Lid(DL)/Tail Gate(TG) and Fender for the Bodies in White (BIW) of S308NB/HB, G01/G11, V818, G60. The workstation diagram is shown in Fig.4. The execution system includes workstations named FL160、FL170、FL180、FL190 in the production lines, among which includes process equipment, pneumatic guns, skids, tools, etc. FL190 was vacant workstation, and the production line is dynamic chain plate mode.

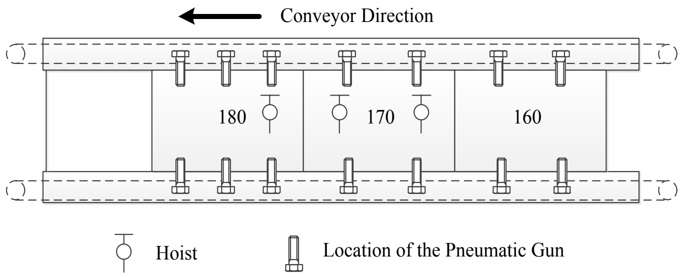

Fig. 4. The Workstation Diagram of FL160-190

Fig. 5. Measurement and Adjustment of G01/G60

The original production process produced five types vehicles (S308NB/HB, G01/G11 and V818) in the common line, in which improper process basically didn't exist. While putting the new type vehicle G60 into production, unreasonable factors in the arrangement of process equipment and the rhythm of process emerged from the renewed process of the common line. The adjustments of TG for G60 were arranged to start from FL160 and then along with the dynamic chain plate until FL180.This procedure required operators to stand on the skid while measuring and adjusting the dimensions. The problem is that the new type vehicle G60 is a sport-utility vehicle (SUV) whose body is higher, however from FL170 to FL180 there are three hoists which may interfere operation and injure operators(see Fig.1). Moreover, three hoists here are indispensable to the process and should not be demolished or substituted.

According to the problem, the solving goal should be one that maintains the advantage of the original system with the multi-type vehicles common production mode, while eliminating the operational safety problems caused by inserting G60, neither making the improved system more complicated or the operation inconsistent with the man-machine engineering, nor introducing new problems during operational process.

3.2 Analysis of U-FES model based on FBS-A

The paper uses the water storage and flood drainage of Yangtze River as the source of analogy. The working process of U-FES shown in Fig.6 describes the evolution of Fitting line from function definition to structure generation.

The function layer describes the process of function decomposition and function semantics definition. The function & effects base of TRIZ supports this procedure. The predefined functions of Fitting line include arranging the processes of assembling and adjusting FD/ RD/HD/DL/TG/Fender and the movement of transporting BIW and Operators. In terms of function structure, the processes of assembly and adjustment include hoists hoist FD/ RD/HD/DL/TG and pneumatic guns screw screws.

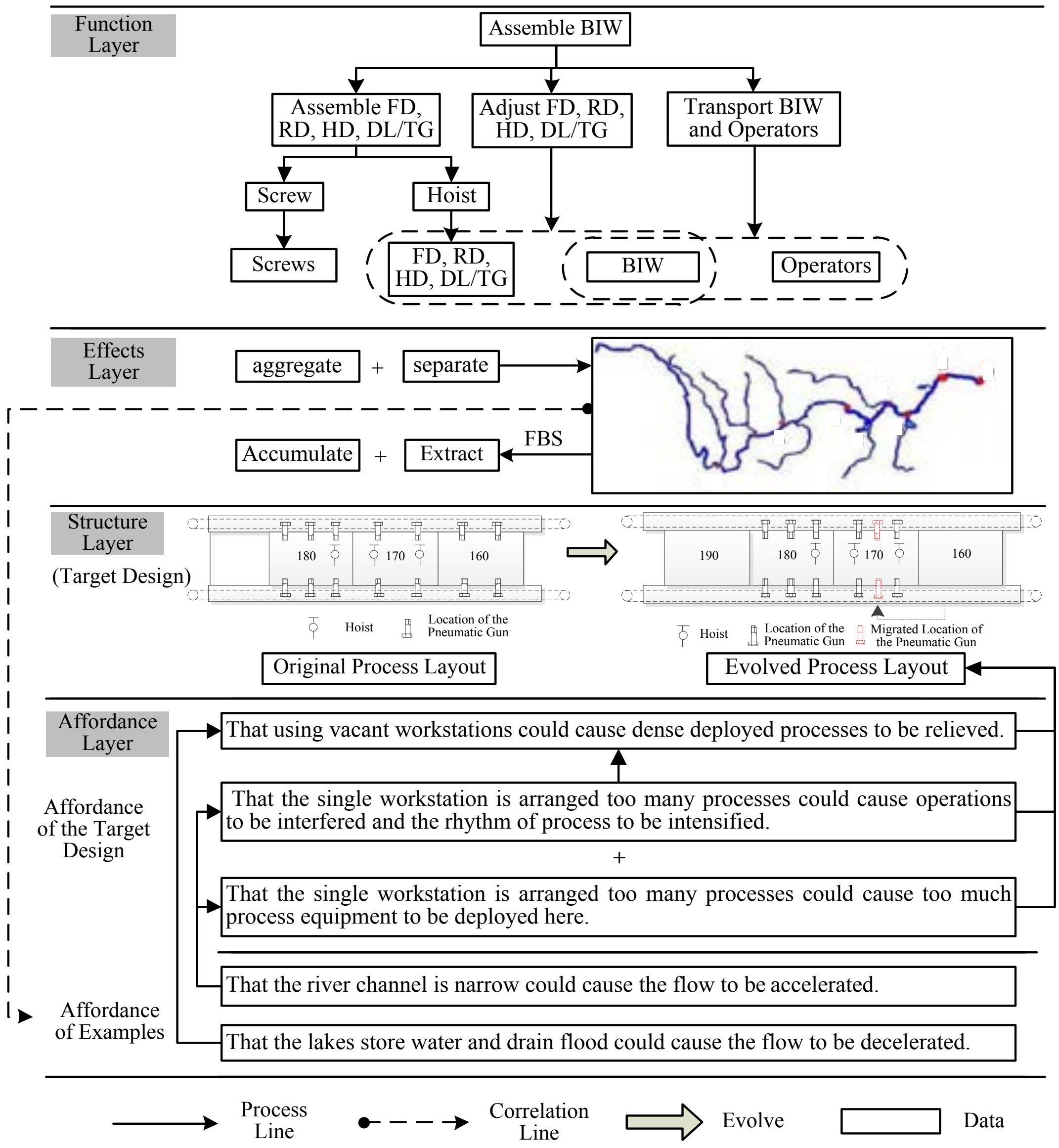

Fig. 6. The working process based on U-FES

The effects layer describes effects based on the function & effects base of TRIZ rebuilt and extended. The effects of the process operation arranged at each workstation include the aggregation of different processes at the same workstation and the separation of different processes at the different workstations. The water storage and flood drainage of river can be thought of as the source of analogy. Yangtze River accumulates tributaries and the flow velocity of its main stream is slower in the broad channel and more rapid in the narrow channel. In addition, the surrounding lakes can store water and drain flood by drawing off the water. The structure solutions of target design can be obtained by analogizing effect examples via structure analogy or FBS.

The structure layer describes the evolution process of structure solutions. This process is driven by UXD and managed by TRIZ. Subsequently the problem is analysed using TRIZ.

The affordance layer describes problems using modal verb. The UXDs obtained from the source design include: 1) That the river channel is narrow could cause the flow to be accelerated; 2) That the lakes store water and drain flood could cause the flow to be decelerated. The UXDs obtained from the target design include: 1) That the single workstation is arranged too many processes could cause too much process equipment to be deployed here; 2) That the single workstation is arranged too many processes could cause operations to be interfered and the rhythm of process to be intensified; 3) That using vacant workstations could cause dense deployed processes to be relieved. Comparing the water storage and flood drainage of lakes in the source design with utilization of vacant workstations in the target design could drive the evolution of process layout.

The FBS-A model layer describes the evolution of process layout, in which TRIZ has been interactively applied. While UXD obtained, the process can be switched to the analysis of TRIZ entirely.

3.3 Analysis of TRIZ

1. Contradiction definition

In this example, the physical contradictions could be defined as follows: On the one hand, in order to pursue the high-efficient production, the dynamic chain plate should move forward so as to ensure that the operators of three consecutive workstations (FL160/170/180) complete the corresponding operations. On the other hand, in order to complete the operations of measuring and adjusting the dimensions, the dynamic chain plate should keep static, the reasons of which are the operator needs to stand on the skid and the static chain plate could prevent three hoists from FL170 to FL180 from interfering operation and injuring operators. Therefore, that motion or statics of the dynamic chain plate is inevitably a physical contradiction.

2. Analysis of inventive principles

Based on UXDs obtained from the analysis of FBS-A, physical contradictions can be solved by the whole & part separation. That is to separate the integrated processes of each workstation so that the processes of assembly and adjustment and the utilization of hoists can be separated.

3. Final scheme for solution

According to the separation method and the combination method, the processes of each workstation are separated and then recombined so as to optimize the process layout. The evolved workstation diagram & migrated scheme is shown in Fig.7. The vacant workstation FL190 has been applied. The initial positions for the processes of assembly and adjustment of DL/ TG for each type vehicle have been migrated to FL190, which is behind the three hoists. The other processes of FL160 have been migrated respectively to FL170/180/190. As a result, the interference to operations and the injury to operators have been eliminated, which accords with the man-machine engineering. Moreover, based on the system substitution method, to rearrange pneumatic guns could be considered. Two of the pneumatic guns in FL160 have been migrated to FL170 for assembling DL of V818 while other two pneumatic guns demolished and substituted by the pneumatic guns in FL180 with the same specification. As a result, the cost of two pneumatic guns has been saved. That could be treated as an UXD which has been applied in the evolution. Through evaluation, the scheme of the evolved process layout satisfies the process requirements, such as security, torque, cycle time, etc. Consequently, the scheme has been already implemented and works well.

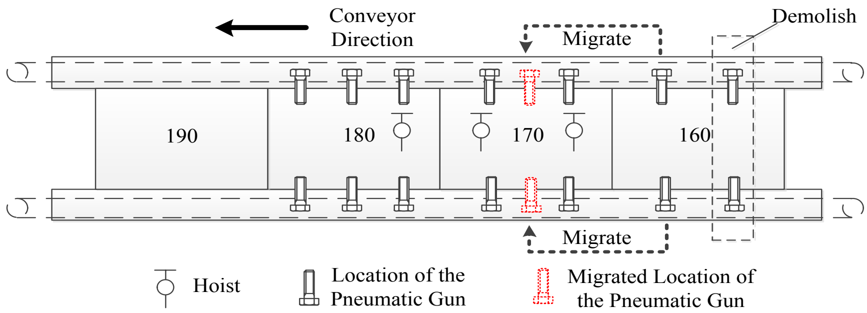

Fig.7. The evolved workstation diagram & migrated scheme

4.Conclusions

The solving process integrating FBS-A representation with TRIZ is able to solve the problems that the knowledge representation of TRIZ is too abstract and the function verbs of TRIZ are too specific. In addition, the method can not only be applied to the innovation of behaviour and structure in the target design but also support the diagnosis of function unit solutions during analogy.

It is necessary to point out that no matter FBS or A in the situated analogy, the cognitive and perceptive process is completed by human so that the means of computer management should be provided to ensure the accuracy of data storage and retrieval. Therefore, the information model based on FBS-A and TRIZ would be an important part of future research.

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STANDARD VDI 4521 PART 3: INVENTIVE PROBLEM SOLVING WITH TRIZ: PROBLEM SOLUTION

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Abstract

Standard VDI 4521 is a German industrial standard and technical guideline for practitioners. It is published in coordination with DIN standardization institute and MATRIZ, the International TRIZ Association. Part 1 was published in 2016-04 and recommends a nomenclature for TRIZ terms. Part 2 was published as a blueprint in 2016-12, it defines and concisely explains TRIZ methods and tools focusing on the analysis phase of the problem-solving process. Part 3 covers the solution phase and will be published by the end of 2017 in draft version. The standard constitutes a reference for researchers, authors, and practitioners of TRIZ in order to establish a common understanding of TRIZ subjects. Tools and methods differing from those described in the standard can be easily described by their differences from the standard.

Keywords: standard; VDI 4521; nomenclature; terminology, glossary

1. Introduction: Standardization of TRIZ

During the past 30 years, TRIZ spread out worldwide and an international community of TRIZ users and developers has grown up. This way, large varieties of subjects of interest have been dealt with and TRIZ has been enriched with influences from various cultures and disciplines. On the other hand, the increase of methods and tools, mixture of TRIZ with non-TRIZ ideas, and translations from one language to another brought along a confusion of terms and contents. This situation is both stimulating and connected with drawbacks as we pointed out earlier [1–3]:

- For students seeking better understanding of TRIZ, it is difficult to compare different sources of literature.
- Beginners limit themselves to single parts of TRIZ and may misunderstand the whole theory.
- Wrong conceptions of TRIZ may evolve, be passed on and be multiplied.

- If the theory is not well understood, methods of TRIZ may be mixed up with other theories and their original conception may get lost.
- Users and researchers need exchange and discussion. For this purpose, they need a common language and understanding.
- In order to present TRIZ as a state-of-the-art methodology, which ought to be part of technical education, TRIZ should have a generally accepted body or core, i.e. a standard.

Litvin, Petrov, Rubin, and Fey therefore compiled a catalogue of standard tools and methods together with appropriate literature into the "TRIZ Body of Knowledge" [4]. Souchkov prepared a comprehensive glossary of TRIZ terms [5] on behalf of MATRIZ and Petrov provided an extensive glossary incorporating input from various schools [6].

After consultation with the TRIZ community and MATRIZ, work on VDI engineering guideline started in 2014 based on a first version of [5]. The first part of VDI 4521 was published in 2016-04 [7] and the second in 2016-12 [8]. Part 3 is under progress and is expected to appear in draft edition by the end of 2017.

There have been TRIZ experts who expressed concerns that a standard might interfere with their work by requiring some sort of certification or restrain future development [1]. This is not the objective of this project and is not usual for VDI guidelines – these are a mere description of the state of the art and anyone may describe the methods he or she used as "according to" or "differing from" VDI 4521 in a certain aspect.

2. Contents of the standard

2.1 Part 1: Fundamentals, terms and definitions

Part 1 contains a glossary of TRIZ terms with their respective definitions, figs. 1 and 2, explains basic concepts, and provides an overview on the general process of problem solving. It lists selected tools and methods and assigns them to the following parts of the standard, which explain them in more detail; finally, a list of recommended literature is given.

Contents Page

Fig. 1 Contents of VDI 4521-1 [7]

2 Terms and definitions

For the purposes of this standard, the following terms and definitions apply:

40 Inventive Principles
last collection of Inventive Principles authorised by *G. Altshuller* published in [1]

administrative contradiction
problem situation in which neither a contradiction nor a solution is evident

algorithm of inventive problem solving (ARIZ)

Алгоритм Решения Изобретательских Задач
algorithm for the solution of a problem with various TRIZ tools which intensifies the problem by reformulating it in a series of steps

Fig. 2 TRIZ glossary defining terms (extract) [7]

The committee critically reviewed the terms in V. Souchkov's glossary, removed doublets, and determined the terms to be included in Part 1. The general guideline was to compare various works of literature – favourably translations of Altshuller's works – and to decide on the most common expression. Terms to be included in the standard were tools and methods that constitute the undoubted state of the art. First of all, these were Altshuller's terms; in addition to those, terms established and described in the literature such as *function analysis*, *problem formulation*, or *root-conflict-analysis* were included. Not included were new tools and tools that do not yet qualify as "general state of the art" due to limited dissemination. The committee would in no way judge the quality of tools and any term that will be more common in the future may be included in a later edition of the standard.

Terms that are closely connected with an individual tool – e.g. the *40 Innovative Principles* – are described together with the respective tool in Part 2 or 3.

2.2. Part 2: Objective, problem definition, and prioritisation

VDI 4521-2 explains TRIZ tools and methods, i.e. tool systems, which are used in particular in the phases of describing objectives, problem definition, and solution prioritization in the problem solving process. However, since many TRIZ tools and methods are versatile and can be used in different phases of the problem solving process, the assignments made in **Error! Reference source not found.** only reflect the typical application. In practice, users will employ and combine the methods and tools in many ways.

Table 1

TRIZ tools with focus on the definition phase

	Type of tool	Description of objective	Problem definition	Search for a solution	Solution selection
Ideality	Objective Creativity	■	■		■
TRIZ forecasting	Analysis	■	■	□	□
Function analysis, function model	Analysis		■	■	
Innovation checklist	Analysis	■	■	□	
Problem formulation	Analysis		■	■	
Root-conflict analysis	Analysis		■	■	□
Cause-effect chains analysis, cause-effect diagram	Analysis		■		
Patent circumvention	Knowledge		■	■	

(■ typical use, □ applicable)

The tools mentioned in Table 1 are explained in a concise manner following the objective to define a tool rather than explain it to a beginner. The standard is not intended to be a textbook for studying TRIZ. Tool descriptions therefore generally refer to suitable literature.

2.3. Part 3: Problem solution

The tools described in VDI 4521-3 concentrate on the problem solution phase. Table 2 represents the subjects treated in this part. Once again, the assignment is arbitrary to some degree.

In the same way as above, we evaluated the literature including available training materials and summarized the state of the art. Some tools have experienced considerable development work during the last decades without general agreement on one version being evident, as is the case with the Laws of Evolution or the Inventive Standards. In these cases, we limited ourselves to describing the last undisputed version, i.e. Altshuller's version.

Table 2

TRIZ tools with focus on the solution phase

	Type of tool	Description of objective	Problem definition	Search for a solution	Solution selection
Contradiction	analysis		■	■	
Inventive principles	knowledge			■	
Anticipatory failure identification	creativity		■	■	
Catalogue of effects	resources			■	
Feature transfer	resources		□	■	
Laws of engineering systems evolution	knowledge	■		■	■
Function-oriented search				■	
Size-time-cost operator	creativity			■	
Resource analysis	resources analysis		□	■	□
Principles of separating contradictory demands	knowledge			■	
Substance-field analysis	analysis		■		
Inventive standards	knowledge			■	
System operator	creativity resources		□	■	
Trimming	resources		■	■	
Contradiction matrix	knowledge			■	
"Smart little people" model	creativity			■	
ARIZ	procedure	■	■	■	

(■ typical use, □ applicable)

3. Challenges to the editing team

In the process of reviewing the state of the art, definitions and agreements showed up which have become common but which in some cases do not seem to be perfectly consistent. The edition of a standard constitutes an opportunity to tidy up organically grown contents and to straighten the systematics. The committee however did not dare to do so and resisted this temptation since we did not consider ourselves legitimated enough. Nevertheless, we would suggest discussing several points at this conference (some were mentioned before in [3]).

- The Engineering system is defined as "Man-made assembly of several interacting elements which meets a purpose." – The aspect of a purpose is crucial because this implies that engineering systems are always open systems and that they serve the needs of their creator. The limitation to man-made objects seems needless, though, since there is no reason to exclude tools and constructions used by animals.
- Field and function: These terms are not well differentiated from each other. According to Bytheway [9], L.D. Miles coined the term of "function" at the end of World War II. Could it be that Altshuller was not acquainted with this concept and therefore chose "field"? Function and Substance-Field analyses would benefit from reuniting both terms.
- In Substance-Field and Function analyses, harmful functions use to be represented by means of an undulated arrow. Common illustration software does not draw this kind of arrows. Could we therefore agree to use another type of symbol, e.g. a double arrow?
- Separation principles – Altshuller mentions four principles in [10]: Separation in space, time, transition states, and system structure. Later publications list varying numbers of principles. The committee arranged them into five: 1 space (where), 2 time (when), 3a relation (for whom), 3b change of conditions (under what conditions), and 4 structure (on which system level). The numbering 1 – 4 respects the common classification, but 3a and 3b are in fact different – so why not five?

4. Conclusions and outlook

The international evolution of TRIZ has reached a level at which determination of the vocabulary and the definition of tools seems essential, so this task has been undertaken by several initiatives. Our committee consisting of some 20 TRIZ specialists has integrated this material with literature and summarized it in standard / engineering guideline VDI 4521. The Association of German Engineers, VDI, and DIN are internationally renowned standardization institutions and facilitated this process. Parts 1 and 2 of the standard have already been published, part 3 will be published by the end of 2017. The international TRIZ community will then be welcome to file suggestions for improvement for 6 months after which period the final version will appear.

All VDI guidelines are revised every 5 years. Later modifications required due to technical progress can therefore be considered in the next edition.

The official version is edited in English and German, a Russian version is being prepared, and additional translations are desirable. Additionally, a textbook as an extended version is scheduled.

Since a standard draws its value from being employed, we would wish to request all authors to kindly refer to the guideline.

Acknowledgements and interests

The committee express their gratitude to several TRIZ masters for kind counselling and to VDI for project management. The committee members do not seek any personal advantage by this project nor are they obliged to any institution who does so.

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SUGGESTION OF METHOD OF DISCOVERING INNOVATIVE IDEAS THROUGH CONVERGENCE OF TRIZ AND BIG DATA SOLUTION

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Abstract

To become a first mover, an individual/company should be able to derive and commercialize realistic and effective ideas that can be recognized in a marker. Although there have been numbers of concerns about how to achieve innovation in each company, no methodology is available yet for first movers to utilize for deriving realistic effective ideas and developing a product using the ideas.

The present paper provides a research on possible application of TRIZ in each company as a methodology for discovering innovative ideas so that an individual/company can become a first mover, wherein TRIZ is a method of generalizing a problem in a case where a problem situation is clear to find a solution therefrom, thereby solving the problem by individualizing the solution.

Considering a question 'what are ideas for discovering innovative ideas leading to the first mover?', some explanations of innovative idea methodology are exaggerated. As an example, it is explained that innovative ideas emerge when an individual/company has an open mind, reads market trends, collects massive amounts of information, and converge various categories.

However, Steve Jobs, who astonished the world with innovative ideas, said "Users do not know what they want, and thus, market research or the like is not necessary," and he really did not do much market research. He also said "Creation is a simple connection of various elements together. If you ask creative people how to work so creatively, they will feel guilty, because their work is not a result of what they actually did, but a result of what they saw." As such, what people call innovative ideas is often not very impressive.

The lesson that the first movers can take from successful innovation cases is that, even if the stride required for innovation is not a big step, a technology having a baby step can be an innovation so long as the technology has a great potential to attract consumers.

TRIZ defines a problem situation, which is well known as an unsolved problem, as a problem. When it is difficult to find a solution easily, TRIZ solves a problem by combining various cases that have already solved the problem. As a result, TRIZ is able to produce a solution to the problem in a totally unexpected manner, and accordingly, new ideas and large numbers of patents are created. As such, TRIZ is available

for solving a problem that seems to have no solution, but it is difficult to link the TRIZ ideas to innovative ideas leading to the first movers. The reason why there is a difficulty may be that only the problem solutions that are already well-known are defined as problems.

Perhaps innovative ideas can start with matters that are not well known. As Steve Jobs said, "Users do not know that they want." That is, when a problem is discovered in a situation where one does not know what the problem is, and the discovered problem is solved, the potential to attract consumers can be a technology for achieving innovation. In this regard, TRIZ can be utilized as a methodology for discovering innovative ideas.

In the present paper, a way of discovering an unknown problem using various methods is discussed, and such an unknown problem discovery therefore is defined as a problem situation of TRIZ by using the most efficient method of finding the unknown problem. Once a problem is defined by TRIZ, the problem is generalized to find a solution by using the process currently available by TRIZ, and the solution is then individualized to solve the problem. According to one or more exemplary embodiments, it is to be proved that TRIZ can be possible utilized by the first movers as a methodology for discovering innovative ideas.

1. INTRODUCTION

1.1 Research Objective

The objective is to expand TRIZ to the scope that first movers can utilize as a methodology of deriving realistic and effective ideas and developing a product using the ideas.

The fast follower strategies have been widely valid in the meantime in the national development and corporation strategies. However, new first mover strategies are now required to compete with the world's leading companies in the fierce global market.

Considering conditions to become a first mover, global sources and globalized creation are required through one's creative and new attempts, such as a business portfolio, a product lineup, a new product development, and so on.

However, blind first mover strategies are at risk in a situation where a market has not been formed yet. In reality, fast movers may not be always winners. Even if the first mover strategies are successful for the development of technology, such developed technology may not be able to enter the global market or succeed in commercialization in the case where the first mover strategies are not recognized in the market.

To successfully produce first movers, realistic and effective ideas that can be recognized in the market should be able to be derived and used for commercialization. Corning Inc., which is an innovating American manufacturer of glass and related materials for 165 years, has created an unfamiliar position named as a chief innovation officer (CIO) three and half years ago. As such, although there have been numbers of concerns about how to achieve innovation in each company, no methodology is available yet for first movers to utilize for deriving realistic and effective ideas and developing a product using the ideas.

Accordingly, in the present paper, it is considered whether the scope of TRIZ can be expanded as a methodology of deriving realistic and effective ideas and developing a product using the ideas to become a first mover, wherein TRIZ refers to a method of generalizing a problem in a certain problem situation or in a situation where consumer's needs are clearly shown, finding a solution, and individualizing the solution to thereby solve the problem.

In TRIZ of the related art, a well-known problem situation is defined as a problem, a contradiction that is problematic in obtaining a result is discovered, and 40 Inventive Principles, Separation Principles, 76 Standard Solutions, Law of Technology Evolution, and the like are utilized to solve a problem. However, in the present paper, an unknown problem situation is discovered and defined as a problem, a contradiction that is problematic in obtaining a result is discovered, and 40 inventive Principles, Separation Principles, 76 Standard Solutions, Law of Technology Evolution, and the like are utilized through problem resolution cases, to thereby proving that TRIZ has possibility to be developed as a methodology that the first movers can utilize to derive realistic and effective ideas and develop a product using the derived ideas.

2. Conditions for innovative ideas

New technology with a great potential to attract consumer's response
The lessons obtainable from cases where first movers achieved innovation are that the stride needed to achieve innovation can be a baby step rather than a big step, so long as new technology has a great potential to bring consumer's response.

According to the contents of the masters of innovation in reality, a department of passenger transport at SNCF, France's national state-owned railway company that has been selected as the Most Innovative Company in the passenger transport service business in 2013, is provided as an example of the cases where first movers achieved innovation. SNCF, which is a leading service provider to high-speed railroads and long-distance railroads in the European market, was under increasing pressure to achieve innovation due to the liberalization of the European rail service market beginning from the opening of the freight railway market in 2007 and the passenger transport market in 2010. Here, Babara Dalibard, a representative who have been managing SNCF since 2010, ordered to set a comprehensive research box including consumer's diverse needs in transportation. That is, the service concept conceived by SNCF was far beyond merely transporting a customer from one station to another station. Such a simple transportation in the railroad service, which is the company's core business, is merely consumer's minimal expectation. What customers want is a service available between a starting point and an ending point of the journey. Here is Dalibard's interview with <<EURAILmag>> below:

"Our goal newly set in the TGV (France's high-speed strain) service portfolio was to save customer's trouble at every step from a starting point to an ending point of the journey, and that is, every step including a process of registering and printing a ticket at home, a process of taking children around at the station, a process of loading a luggage, and so on."

In addition, Dalibard also says "our goal is to improve customer's travel experience by minimizing their inconvenience that they may feel from their departure point to destination." In this regard, SNCF has created an idea portfolio, which refers to the most promising concept (i.e., the most potential ideas to bring consumer's response) selected from the research box.

3. Beginning of discovering innovative ideas

Discovery of ideas that can bring consumer's response starts with discovery of consumer's hidden needs.

According to the exemplary embodiments above, ideas and new technology needed for innovation are deemed to be a combination of both technical and consumer perspectives. In this regard, the discovery of ideas that can bring consumer's response is deemed to start with the discovery of consumer's hidden needs.

Various methods of discovering unknown problems

The present paper sought to discover ideas that can bring consumer's ideas by finding out effective ways to discover unknown problems.

As a target for the discovery of hidden needs, a smartphone is selected. The smartphone is selected because it is no exaggeration to say that the smartphone itself has no known problems as a result of the repeated development to the point where a compact camera lost its place in the market.

In the present paper, considering the discovery of ideas that will revolutionize a camera of a smartphone (hereinafter, referred to as a smartphone camera), many attempts are made in various ways to discover unknown problems as follows.

3.1 Discovery of unknown problems based on Event Exploration

First, events that occurred through a consumer's smartphone camera are subjected to exploration (Event Exploration).

The consumer's needs are discovered through a smartphone camera are listed according to the events being occurred, and then, summarized in terms of unknown problems according to each of the consumer's needs.

Table 1

Discovery of unknown problems based on Event Exploration

Event	Customer's needs	Unknown problems
Bedtime	I wish to shoot pictures of events that happen while I'm sleeping	I wish to know specific events that happen while I'm sleeping
Meal time	I wish to know calories of food at a table by using a camera	I wish to know calories of food at a table without a need to calculate the calories
Hanging out with friends	I wish to take a picture with a friend	I wish to record moments with a friend by using a (nearby) camera without a need to take an action of using a camera to take a picture.
Driving to work	I wish to record/remember a road I drive	I wish to record a driving route by using a camera while a car is moving

However, when the discovery of unknown problems based on Event Exploration is used as a method of discovering unknown problems by analyzing individual's behavior patterns, a target for such a method is limited. In this regard, there is also a limit to finding problems for deriving innovative ideas.

3.2 Discovery of unknown problems based on Group Activity

Second, as a way to find out unknown problems, group activities are proceeded (Group Activity). Participants are divided into two groups, and have an interview. 38 participants selected from college students, office workers, or power users are interviewed, and consequently, 690 unknown problems are discovered.

Table 2

Group Activity interview

Stakeholder VOC	Orthodoxies VOC
"I wish to have a simple setting procedure"	"I need a PC for editing"
"I do not want to forget emotional memories of the moment I shot"	"I do not pay attention to a guide even if it is provided"
"I want to express the color I feel"	"A high-quality picture has to be taken by using a DSLR camera"
"I wish to have a clear picture"	"A good picture can be taken under a basic camera mode"
"I hope I can connect a camera with other display devices"	"A filter of an application camera is better than a basic filter of a mobile phone camera"

As a different group activity, the participants are subjected to an observation investigation. In detail, at an amusement park, the participants who take a picture by using a smartphone camera are observed for one day. Consequently, 28 unknown problems are discovered from 506 pictures being observed.

Fig 1. Observe users using smartphone cameras

Table 3

Discovery of unknown problems based on Group Activity

A shutter button on a screen is mainly used
A wide viewing angle is desired
Folding/unfolding a selfie stick is inconvenient

Based on the unknown problems obtained from the participant's interview and the observation investigation, Idea Workshop was proceeded. Here, members consisting of ordinary citizens, college students, and TF members who participate Group Activity define 111 problem situations among the unknown problems, and accordingly, they can create an idea sheet on the basis of a simple solution concept.

Fig 2. Idea workshop to discovery unknown problems

Table 4

Simple Solution from unknown Problems

No.	Unknown problems	Simple Solution
1	I wish to have a picture that expresses well the atmosphere I want	Enhanced filter function
2	I want to edit a picture (suitable for scenery, portrait, or the like)	Enhanced filter function
3	I want to share a picture easily with people I want	Sharing function
4	I wish I had no (hand) blur.	Blurriness in pictures
5	I wish to receive meaningful information by recognizing a picture	Recording function
6	I do not want to forget the feeling of the moment I shot	Recording function
7	I want to record my child's growth	Child-related function

The group activities that were proceeded for 2 weeks in terms of the discovery of unknown problems collected usage cases from various user types and discovered numbers of ideas. However, such activities were time-consuming methods, and were only suitable for group members rather than individuals.

3.3 Discovery of unknown problems based Big Data

Third, as a way to find out unknown problems, big data is utilized (Big Data). Big Data has focused on so far finding out factors that influence the future by analyzing the data of the past. However, in the present paper, it is assumed that there will be many unknown problems in numbers of social data, and thus, a free big data analysis tool is used to attempt the discover of unknown problems therefrom.

Attempts are made to discover unknown problems by using a tool that analyzes search frequency available from a portal site.

Google Trends and NAVER Trends each provide a tool that analyzes search frequency of a search term for free. When the term 'mobile phone camera' is analyzed by the tool of Google Trends, the search frequency of the term is increased on the release date of Galaxy phone. In this regard, it is understood that a camera is an important factor of a mobile phone to consumers, but any unknown problem related to a mobile phone camera cannot be discovered therefrom.

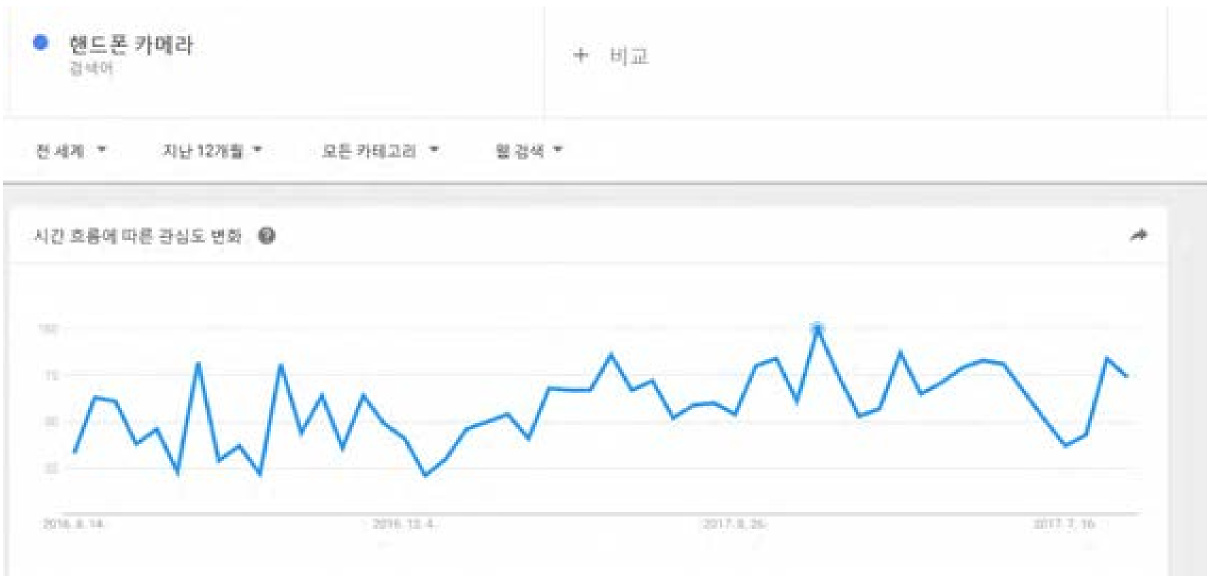

Fig 3. 'mobile phone camera' is analyzed by the tool of Google Trends

By NAVER DataLab (http://datalab.naver.com), a search term can be used to search data. For example, when a search term 'mobile phone camera' is entered into a search box, at least 357 patents or statistical data on the mobile phone camera are found.

Provided are examples of unknown problems that can be discovered by DataLab analysis.

Table 5

Discovery of unknown problems based on DataLab analysis

Patents	Unknown problem
PORTABLE MOBILE PHONE CAMERA LENS FOR MACROPHOTOGRAPHY	It is difficult to take close-up photographs with a mobile phone camera
REAL-TIME STORING METHOD USING CAMERA OF MOBILE PHONE ON WIRELESS COMMUNICATION	A storage space is limited after shooing with a mobile phone
INFORMATION PROVIDING SERVICE METHOD USING MOBILE PHONE CAMERA AND IMAGE SEARCHING/DISCRIMINATING SYSTEM, PARTICULARLY FOR SEARCHING MORE ACCURATE INFORMATION QUICKLY AND EASILY	It is difficult to search/discriminate photographs taken with a mobile phone
GATE OPENING/CLOSING DEVICE USING A DOOR LOCK CAMERA AND VIDEO COMMUNICATION OF A MOBILE PHONE, CAPABLE OF OPENING A DOOR AFTER IDENTIFYING A FACE OF A DELIVERER	An application plan other than a mobile phone camera is considered

Through the analysis of search terms by Big Data, patents and statistical data on the mobile phone camera are easily collected, and accordingly, unknown problems related to the mobile phone camera can be also discovered from the collected data.

As another way of Big Data analysis, social data is analyzed.

Big Data of Twitter or blog can be analyzed in real time.

Fig 4. 'mobile phone camera' Associative map

Fig 5 'mobile phone camera' Social Data Analytics

Table 6

Discovery of unknown problems based on Social Data analysis

Summary	Contents	Unknown problem
Possibility of a mobile phone camera to be wrongfully used (crime)	It was annoying to go to other places to take a picture because somebody noticed me that "someone behind you was taking a picture of your leg with a mobile phone".	A careful attention is needed not to be exposed to unpermitted shooing
Limited image quality with uneasy set ups	When using a mobile phone camera, the color of the picture was either bright or dark upon the electric light or angle.	A professional-like effect is desired even if taken inattentively
Possibility of a mobile phone camera to be wrongfully used (crime)	It was annoying to go to other places to take a picture because somebody noticed me that "someone behind you was taking a picture of your leg with a mobile phone".	A careful attention is needed not to be exposed to unpermitted shooing
Limited image quality with uneasy set ups	When using a mobile phone camera, the color of the picture was either bright or dark upon the electric light or angle.	A professional-like effect is desired even if taken inattentively

Possibility of a mobile phone camera to be wrongfully used (crime)	It was annoying to go to other places to take a picture because somebody noticed me that “someone behind you was taking a picture of your leg with a mobile phone".	A careful attention is needed not to be exposed to unpermitted shooing
Limited image quality with uneasy set ups	When using a mobile phone camera, the color of the picture was either bright or dark upon the electric light or angle.	A professional-like effect is desired even if taken inattentively
Possibility of a mobile phone camera to be wrongfully used (crime)	It was annoying to go to other places to take a picture because somebody noticed me that “someone behind you was taking a picture of your leg with a mobile phone".	A careful attention is needed not to be exposed to unpermitted shooing

By the free Big Data analysis tool, activity trends uploaded by various age groups around the world in portal sites, patents, main SNS messages, and the like can be collected in a short period of time, and the analyzed results are visualized as trends, search terms, and the like. As such, in the present paper, various unknown problems of the mobile phone camera can be discovered.

The limitations of finding a problem with a limited target of Event Exploration, which is the first way to discover unknown problems, are overcome. In addition, based on Group Activity and Workshop, which is the second way to discover unknown problems, it is confirmed that Big Data analysis enables the discovery of unknown problems without a need of much time and effort, through analysis of social media activities of various age groups around the world in a short period of time.

The unknown problems obtained by the discovery above are then defined as problem situations of the existing TRIZ, a contradiction that is problematic in obtaining a result is discovered, and 40 Inventive Principles, Separation Principles, 76 Standard Solutions, Law of Technology Evolution, and the like are utilized to solve a problem.

The results obtained by solving the problem through TRIZ are registered with a number of patents, but for security reasons, a detailed problem solving process is not described herein (if disclosure of the process is required, further consultation is needed).

However, a variety of ways to discover unknown problems are introduced in the present paper, and more particularly, it is confirmed that application of Big Data is the most efficient way to analyze problems faced by various people around the world in a short period of time. When an unknown problem situation is discovered and solved by TRIZ, rather than solving a well-known problem situation, it is confirmed that innovative ideas that people has ever through of can be discovered.

4. Conclusion

The present paper suggests a way to solve an unknown problem, rather than a well-known problem, so that TRIZ can expand its scope as a methodology of deriving realistic effective ideas and developing a product using the ideas leading to the first mover. In particular, as the best way to discover unknown problems, application of Big Data is introduced.

The application of Big Data enables to the discovery of unknown problems, and when combined with the existing TRIZ, TRIZ is more advanced in terms of deriving innovative ideas. Therefore, TRIZ can be used as a methodology of discovering innovative ideas that can be recognized in the market in the future.

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TEACHING CREATIVE PROBLEM SOLVING AND DECISION MAKING. UNIVERSITY vs WORKPLACE

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Thinking is the hardest work there is, which is the probable reason why so few engage in it.
— Henry Ford

Fantasy, abandoned by reason, produces impossible monsters; united with it, she is the mother of the arts and the origin of marvels.
— Goya

Schools are training students for a world that doesn't exist.

Abstract

There are not so subtle differences between teaching creative technical problem solving and decision making at a university and a workplace. The differences in life and practical experiences, the emotional makeup, the level of motivation, etc., present a distinct set of challenges.

But one observation, this author made throughout his many years of experience teaching TRIZ based creative problem solving, practically, very few people in either group possess sufficient level thinking skills or an ability to learn new things.

In this paper, the author will discuss various approaches, developed while teaching creative problem solving.

Key words: *TRIZ, creative problem solving, thinking skills, motivation enhancing approaches*

1. Introduction

We live and act in an unpredictable environment full of dangers and unexpected opportunities, and we must not allow the unexpected to suddenly derail our efforts.

Creative work is, perhaps, one of the most difficult and complicated ones, however, until recently, there was no technology, to aid with this work, and people had to rely on the method of trials and errors when looking for innovative solutions, wasting weeks, months and years. This situation was tolerable at the initial stages of the development of science and technology, but from the end of the 19th and the beginning of the 20th century it became dilatory force in the development of the society. Then, various methods for activation of creative thinking were introduced into this process. Let's name some of them – brainstorming, method of focal objects, synectics, method of control questions, morphological analysis and others. Unfortunately, these methods represent mere improvements to the method of trials and errors.

Enter TRIZ! TRIZ was introduced to the Western World in the late 1980s. First in Europe, and in 1991 in the USA. Once several companies realized the power of TRIZ they started to look for ways to introduce TRIZ to their organizations. Immediately they were faced with a problem of an existing approach to workplace training, a 2-3 days' seminar/workshop, vs. a much longer process of TRIZ training. Some, like Proctor and Gamble in the USA and Samsung in South Korea, simply hired experienced TRIZ practitioners from the former Soviet Union. Some others tried a 2-3 days' seminars/workshops, offered by several newly minted TRIZ instructors, who quickly appeared in the USA and other Western countries. However, it did not take long for the industry to realize that 2-3 days of training is insufficient for their associates to develop skills, necessary for application of TRIZ tools for solving complex problems. In addition, the urge to teach TRIZ nearly completely displaced the real need – the need to teach creative problem solving.

Also, many times I was asked: "*…are there a book I may read and learn TRIZ*?" My answer to this question is as follows: TRIZ does not render the creative experience, it suggests it! Thus, reading TRIZ book doesn't make you an expert problem solver – solving problem, using TRIZ tools, does. Just like reading a book on swimming doesn't teach you how to swim – jumping into water and swimming does.

2. What to teach

Automation, artificial intelligence, machine learning. Many experts disagree on what these modern technologies will mean for the workforce, the economy and our quality of life. But where they do agree is that technology will change (or completely take over) tasks that humans do now. The most pressing question, many economists and labor historians say, is whether people will have the skills to perform the jobs that are left.

For example, when ATMs were introduced in the 1970s, people thought they would be a death knell for bank tellers. The number of tellers per bank did fall, but because ATMs reduced the cost of operating a bank branch, more branches opened, which in turn hired more tellers. U.S. bank teller employment rose by 50,000 between 1980 and 2010. But the tasks of those tellers evolved from simply dispensing cash to selling other services the banks provided, like credit cards and loans. And the skills those tellers had that the ATMs didn't — like problem solving and decision making — became more valuable.

"*We are moving into an era of extensive automation and a period in which capitalism is just simply not going to need as many workers*," said Jennifer Klein, a Yale University professor who focuses on labor history. "*It's not just automating in manufacturing but anything with a service counter: grocery stores, movie theaters, car rentals ... and this is now going to move into food service, too.*

What are we going to do in an era that doesn't need as many people? It's not a social question we've seriously addressed."

Instead of worrying about the mass unemployment a robot Armageddon could bring, we should instead shift our attention to making sure workers — particularly low-wage workers — have the skills they need to compete in an automated era, says James Bessen, an economist, Boston University law lecturer, and author of the book *Learning by Doing: The Real Connection Between Innovation, Wages, and Wealth.*

"*The problem is people are losing jobs and we're not doing a decent job of getting them the skills and knowledge they need to work for the new jobs*," Bessen said. And this is not just low paying occupations phenomena. People with college degrees, when losing their jobs, don't have the skills for a new carrier path. Nor do they possess the necessary skills for learning a new profession. Addressing this skills gap will require a paradigm shift both in the way we approach job training and in the way we approach education, he said.

"*Technology is very disruptive. It is destroying jobs. And while it is creating others, albeit not as many, because we don't have an effortless way to transition people from one occupation to another, we're going to face increased social disruption*," he said.

In this new age, Bessen said, we can't treat learning as finite.

"*We need to move to a world where there is lifelong learning*," he said. "*You have to get rid of this idea that we go to school once when we're young and that covers us for our career. ... Schools need to teach people how to learn, how to teach themselves if necessary*."

With this said, the need to teach Creative/Problem Solving, Critical/Evaluative, and, as important, Practical/Learning skills to next generation of workforce is self-evident. Yet, very few learning institutions are engaged in teaching these skills.

2.1. Creative skills

Until about 100 years ago, creativity has been considered as something attributed to a very few especially talented people. Today, creative problem solving is a 21st Century survival skill.

Creative work is, perhaps, the most difficult and complicated one, however, until recently, there was no technology, to aid with this work, and people had to rely on the method of trials and errors when looking for innovative solutions, wasting weeks, months and years. This situation was tolerable at the initial stages of the development of science and technology, but from the end of the 19th and the beginning of the 20th century it became dilatory force in the development of the society. Then, various methods for activation of creative thinking were introduced into this process. Let's name some of them – brainstorming, method of focal objects, synectics, method of control questions, morphological analysis and others. Unfortunately, these methods represent mere improvements to the method of trials and errors.

In the early 1940s TRIZ started to be formed in the former Soviet Union. This theory was based on existing laws of the development of technical systems, rather than on human intuition. For the first time in human history it was recognized that technology, as a system, develops in accordance with objective laws, independent of the wishes of engineers and inventors. The knowledge and utilization of these laws allow any educated person to come up with higher level inventions purposefully and with little time. With TRIZ, engineering creativity is accessible for any educated person, not just for the elite.

TRIZ is a young science, but hundreds and thousands of highly effective inventions have been already created with its help. Many TRIZ principles are successfully used in scientific research, medicine, pedagogy, business and many other areas. It should be noted here that TRIZ is not a substitute for individual creative capabilities. It organizes and improves the effectiveness of utilization of existing knowledge.

Genrikh Altshuller, a Russian scientist and researcher, is the author of TRIZ. At the present TRIZ is being developed with the efforts of many of his students and followers in Russia and abroad.

2.2. Critical/Evaluative skills

Mentions of critical thinking in job postings have doubled since 2009, according to an analysis by career-search site Indeed.com. The site, which combs job ads from several sources, found recently that more than 21,000 health-care and 6,700 management postings contained some reference to the skill.

Unfortunately, many people believe that critical thinking is about negativity or criticizing the work of others. Contrary to widespread belief, being a critical thinker doesn't mean giving constructive criticism. Instead of focusing on producing critique, a critical thinker would first and foremost observe, analyze and gather information necessary for forming a consistent, thorough and logical opinion.

Yet, most of our thinking lacks direction, is uninformed or downright prejudiced. And these are the obstacles to critical thinking. Critical thinking is about actively and skillfully analyzing, synthesizing and applying information generated by observation, experience, reflection or reasoning. It is also about evaluating information for reaching an answer or conclusion. Critical thinking is the thinking in which thinkers improve the quality of their thinking by thoroughly analyzing the given information and situation. And the quality of all we do and the decisions we make depend precisely on the quality of our thought. Excellence in thought, however, must be systematically cultivated – which is precisely why critical thinking is of extreme importance. Critical thinking is an essential part of creativity, because we need this kind of thinking if we want to evaluate and improve creative ideas. This kind of thinking is compatible with the so called "thinking-outside-of-the-box".

At the end of the day, critical thinking is the use of those cognitive skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned, and goal directed. Critical thinking is about improving one's judgment for being a better problem solver and/or decision maker.

2.3. Practical/Learning skills

Earlier it was mentioned that education is not a finite process. Learning must become a lifelong activity. In my and my colleagues practice, one of the biggest obstacles to overcome is nearly complete lack of learning skills in older adults. Same is observed with grade school and university students. The entire educational process is founded on rote memorization. And for a good reason – to teach thinking skills teachers/professors must be able to think themselves. There are a few natural born thinkers, the rest of us must be taught to think, but how? Most educational programs are geared towards memorization of facts and, then, answering questions. Yet, people don't learn by answering questions, people learn by asking questions. The present-day conviction among educators is that students don't know what questions to ask if they don't know anything about a subject. Therefore, most educational processes start with a lecture. Nothing could be further from the truth. Just spend a few minutes with a 3-year old. They don't know much about anything, yet, their questions are like a rapid fire out of a machine gun. So, to teach learning skills we need to foster curiosity and to encourage/teach asking questions.

And nothing motivates as much as the satisfaction of a personal discovery. It doesn't have to be an earth shattering discovery, but something new and interesting for you. One of the ways to discover is to solve a problem one never solved before. An open problem, which may be solved in a variety of ways, each solution representing a specific situation and/or condition.

3. How to teach

Here we face one of the most critical issues concerning fostering creative and critical thinking skills. Which method/technology best suited for teaching problem-solving? A recent literature review revealed over 150 various methods, claiming their superiority in this endeavor. But first we need to agree that no single method/technology is equally potent in every situation.

Here we are looking at two vastly different environments: a workplace education/training and a university setting. The only thing these two have in common is the desired result – the well-developed capacity to find a way out of a tight situation. In other word, the ability to solve an open problem in a best viable way under the circumstances.

Psychological inertia and associated linear thinking are two biggest obstacles to creativity. The weight of knowledge holds down the lid on creativity and linear thinking is necessitated by the perceived need to stay focused.

Staying focused, according to many psychologists, is inferior to mind wandering when creativity is in order. Relationship of mind wandering to creativity and future planning suggests its real value. However, there are strategies which may minimize the downsides of mind wandering without disabling its productive powers.

For many reasons, workplace is superior to university setting for teaching creativity/problem solving. One of the biggest reasons is that company associates are normally relieved of any other duties while participating in training. University students, on the other hand, are always busy, for they normally take 3-4 courses per semester. Being busy is very detrimental to creativity. Busy people tend to employ linear thinking; creativity calls for dynamic thinking. In addition, TRIZ training in a workplace has much longer history than at a university. Thus, the process evolved as an all-day affair vs. little over one-hour class period. This timing requires different approach to material delivery.

Critical thinking in a workplace often comes naturally due to the need to implement solutions. In a university, critical thinking needs to be emphasized, which is somewhat more difficult.

So, here we have an acute issue: on one hand, creativity calls for relaxed, dynamic thinking, on the other, TRIZ requires purposeful, concentrated thinking mode. The solution is within TRIZ process, which offers the plethora of approaches for minimizing psychological inertia and a dual thought process – creative and critical at the same time. Ideality and IFR are only two of those. In fact, in many problem-solving situations one or another client team member would exclaim: "…how can you state this nonsense with a straight face". They refer, of course, to the fact that most ideal solutions are not possible due to various laws of nature. Yet, the process of elimination helps to arrive at a viable solution much faster.

4. Conclusion

While in both environments we aim at the same result and project based process is preferred, there are not very subtle differences between the two. In the table below the author summarizes his view on this issue.

Table 1

Position/activity	Workplace	University
A problem	Real life technical or business issue	Study problem from instructor's portfolio
Is the problem solvable	Not known until problem-solving process is engaged	The instructor knows the most plausible solution
Creativity	Developed in the process of problem-solving	Developed in the process of problem-solving
Critical thinking	Necessitated by implementation	Needs to be developed in students' minds
Timing	Usually, a weeklong of an all-day process	An academic hour many times over
Team work	Teams formed based on the nature of issue	At the start of class, using various methods
Desired outcome	The best, economically viable solution	The best possible grade
Long lasting result	Very few become "addicted" to the process	Very few become "addicted" to the process

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THE HERO'S JOURNEY AS A FRAMEWORK FOR LEARNING AND USING TRIZ

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Abstract

The "Hero's Journey" from Joseph Campbell and Christopher Vogler describes a basic dramaturgical concept that is found in Myths, Fairy Tales, Novels and Movies. Campbell discovered that Myths and stories have similar structures which are independent from their cultural backgrounds and origins. This structure can be found in all successfull, great stories and therefore resembles an archetypical pattern: The Hero faces a threat or is confronted with a challange which forces him to go on a journey to solve the problem or master the challenge. On his/her way, the Hero faces a number of tasks which at times seem insurmountable. But finally the Hero prevails and he masters his challenges by reaching an increase in knowledge, combining his own potential with external gifts.

The „Hero's Journey" can be compared with the situation that lots of TRIZ beginners and learners as well as people who design or work in innovation processes are confronted with.

The paper wants to examine the hypothesis that the "Hero's Journey" is an analogy to learning and applying TRIZ as well as an analogy for the innovation process itself. Therefore, the Hero's Journey can be used as a strategy on how to tackle obstacles and difficulties on the way to breakthrough solutions. The related imagery of the Hero's Journey also addresses the recipient on an emotional level, leading to a much higher motivation and stabilizing effect on their perseverance to learn and apply TRIZ as an effective part of systematic innovation efforts.

Keywords: Learning TRIZ, "The Hero's Journey", motivation, obstacles, invention, creativity, organisation development, innovation process

1. About The Hero's Journey

The term myth stands for tradition, a saga or a narration from e.g. prehistoric times of a nation or can be related to a person, an artifact or an event which are often glorified and reach a legendary character [1].

When someone first comes into touch with TRIZ, there are also myths. For example, the tale about how Altshuller managed to survive the Vorkuta prison camp. According to the myth Altshuller had to endure torture by sleep deprivation. A guard regularly checked if Altshuller was awake by checking if he could see the white of his eyes, indicating the eyes are still open.

Altshuller managed to solve this problem by using cigarette paper which he put on his eyelids, creating the illusion of opened eyes while he was sleeping with his eyes closed. With this story of Altshuller surviving the prison camp it is easy to achieve a high activation potential in an audience to explain the concept of Physical Contradictions. [2]

1.1 The Hero's Myth

Myths appeal to us human beings, they make us listen and reach us not only on a cognitive but also on an emotional level, and we are happy to pass them on.

The Hero's Myth has been described by American myth researcher Campbell. He analyzed fairy tales, dramas and myths from different cultures and eras and discovered one common, underlying basic pattern for human development that he described in the dramaturgy of the hero's journey, structured in many steps and phases. [3, 4]

Myths rank among early cultural form of dissemination of knowledge used mainly by those cultures without writing. Commonly accepted wisdoms, the "moral of the story", were passed on and thus conveyed to younger generations or other communities.

Campbell showed that heroes are not born, but develop their forces and strengths by mastering the different challenges during their hero's journey, growing and maturing on their way.

Campbell's path on which heroes go is always the same and consists of 17 steps which are summed up in the following quote:

"During departure, there is calling versus refusal. The hero still feels well and secure in his world. But the something happens. Enforcedly or of his own free will the hero start the adventure into the unknown. This is only possible if he gets into something foreign, uncomfortable, difficult and if he disengages himself from the old, known world. The mentor provides the necessary resources, making it possible to cross the first big threshold into the unknown. The path of trials in the land of the adventures outlines the difficult tasks that the protagonist at this time already (or not yet) solves. He overcomes the biggest fear in the decisive trial, and the reward provides the power to cross the second threshold back to normality. The way back shows how the difficult way back stabilizes the newly achieved skills. These skills get integrated in the daily routine. As a master of two worlds the hero is empowered to act when the new state is a matter of course." [5]

Later on, Vogler summarized Campbells sequence in 12 stages which today are commonly used for developing scripts for screen-plays [6]. Additionally, these phases of the Hero's Journey are widely used in the area of personality development, Coaching and even in organizational development.

1.2 Phases of the Hero's Journey

Vogler's established representation of the Hero's Journey in 12 steps contains the following stages:

1. **The Familiar World**
   The familiar world is recognized as insufficient, dull and boring, but the protagonist is not yet aware of the significant deficiency.

2. **Call of Adventure**
   By meeting a “Herald” the protagonist slowly develops a desire for change. The previously unconscious deficiency slowly gets noticed, but still is largely fuzzy and undefined.
3. **Denial and Entanglement**
   Giving up something familiar does not come easy to humans. Mostly it is combined with trouble and when faced with an upcoming change denial and hesitation increase. Internal and external voices gain influence and obstruct the progress.
4. **Meeting the Mentor and crossing the Threshold**
   At this time a Mentor comes into play. With his/her help the protagonist crosses the threshold of refusal and moves on into the “unknown land”.
5. **Tests, Allies or Foes?**
   On his journey the protagonist has to pass tests and he will meet allies and foes. Only by this situation the true extend of the journey gets visible.
6. **Revelation**
   While the protagonist solves his tasks his potentials and talents get revealed and his life task gets clear.
7. **Lifting Treasures**
   He/she acquires those new skills and abilities that are needed to safe the old “familiar world”.
8. **Refusing to return**
   With the newly gained knowledge the protagonist refuses to go back to the old world and the everyday life. Will there even be a possibility to apply the new skills? Reluctance to return rises.
9. **Decision to return**
   Finally internal or external motives persuade the protagonist to return.
10. **The way back und crossing the threshold to the daily routine**
    Back in the daily routine the hero is facing lack of understanding and distrust.
11. **Awareness of two Worlds**
    The difference between the two worlds “Adventure” and “Daily life” become apparent. He/she starts to connect both worlds by integrating the new knowledge into the old world.
12. **Sharing the Experience [Allies, opponents?]**
    Finally the protagonist succeeds in sharing the new skills, knowledge and his experiences with the old world, thus changing it. [7]

Independent of the task, an arc of suspense is created during the hero’s journey. This escalation to the dramatic is the difference to “normal” projects of classical approaches. When applied in the context of a business project, the artistic-aesthetic concept of the hero’s journey consciously uses exaggerated emotionalization and lengthening of the process in order to visualize contradictions and areas of conflicts instead of rationalizing and building structure. By this means participants of the “journey” become impersonators of feedback scenarios, fears get visible and discussable, at the same time everyday situations get emotionally charged. As a part of surprising arrangements, associations and fantasy practices the participants get new experiences. Their inner worlds that seemed to be forgotten open up.

1.3 Example of a Hero's Journey to TRIZ

The following example shows the typical story of a beginning TRIZ student. While being fictitious, the story incorporates experiences of several real people we trained and met during workshops.

"*My life in the R&D department is quite demanding and tiring at the same time. Again and again we need to solve problems to fulfill new customer requirements. This is on the one hand an exciting job, but it is also stressful. It is like this in the whole 18 years of my career. We are forced to come up with new things, at the same time costs need to be decreased and the new products should be more and more innovative. Again and again, because the solutions quickly become insufficient to our customers – and because we always managed to deliver new solutions. But over time*" - he sighs – "*it's getting overwhelming. All this struggle to increase the efficiency by a mere 0,5%. All the attempts and trials. The roundabout turns faster and faster. Every now and then I feel like we are expected to perform magic to fulfill the demands. No wonder: sometimes I long for means to ignite my creativity so I can perform better and escape this misery more easily. But what can this magic potion be?*"

One day a colleague tells his teammates about a new kind of transmission. A true innovation it is said to be. By using "movable teeth" and somehow "turning the gears upside down" the efficiency has been increased by multitudes. "*But how is this possible? With which magic wand did the developers come up with such groundbreaking ideas and this unimaginable solution?*" Hans asked himself while mulling over the optimization of a motor. "*I want to be such a great inventor as well!"* His research leads him to TRIZ – a methodology that is said to be based on analysis of patents. The inventors of TRIZ had the intention to enable individuals to come up with inventive solutions faster and more easily. "*Sounds interesting…*" Hans was excited. He looked for a training and found a course that even said to issue an internationally acknowledged certificate. But doubts started to set in: "*Hmmm… if it really is a good idea to participate in such a training? And the cost… what will my boss say when I ask him for the training? I'll be missing three working days…*" he pondered. „*Maybe it is not such a great idea to expose myself like this after all. Maybe the others think I am not smart enough and I need such a method to help me get ideas? Won't do that… but then again, it really sounds interesting, and it is based on real patents… maybe… or better not?*"

Daily routine continued as usual. Then one day a guy from the sales department dropped by and showed us this part: "*Look what our competitor managed to come up with!*" and indeed, the competitor launched a new motor that was much smaller and had double the power of previous versions. "*How did they do this?*" the others wondered. Hans felt insecure but at the same time defiance grew "*We can do this as well, and better!*". The same day he went to his boss and requested the training.

Hans was relieved to leave for the training as his scoffing colleagues started to get to his nerves. At the training, he met other developers that had quite similar experiences in their work lives. "*Everything gets faster and we have to come up with clever solutions more and more frequent.*" Lamented Thomas, who was in his first job, fresh from university. Product manager Gloria added that competitors from Asia already produced excellent quality. Moreover, the time her team needs to come to a decision was much too long. "*I hope TRIZ can help me getting a better feeling for a good direction for our product development.*"

They all were excited to get to know this "new" methodology. But it was harder than they first thought it would be. Changing the way of thinking was really tough work - all the new terms and definitions, Functions, Substances, Fields, Systems, Resources. And all but Hans were not used to learning anymore. "*My brain starts to get muscle ache!*" Gloria moaned. "*This is really complex matter.*" Thomas sighed when they spoke about the requirements to pass the test for the certificate. "*And it is only the first level?*" he laughed. But they worked together, discussed the steps and approaches of the TRIZ tools they learned and helped each other with their first training assignments. "*How will it be when we first work on our own real problems?*" asked Hans. But first, they needed to get through the test. Afterwards they were a bit surprised – "*I didn't expect that I could complete the exercises so smoothly. It is really exciting to see how differently the thoughts are guided when we follow the TRIZ systematic: I already start to see some possibilities I didn't realize before! Great!*" Thomas and Hans were happy. Gloria agreed. „*In the future I will check our new concepts if they are able to solve a crucial contradiction for our customer – then I know we have a good and promising solution. That gives me a good feeling, and I am sure we will have a much clearer base for our decisions!*"

"*However*" Hans said "*I have some concerns when I come back to our department and should explain everything to my colleagues. After all I only just begun to understand a bit of TRIZ myself. How should I be able to answer all questions, let alone knowing from the get-go what is the right path to a solution?*" On the last day of the training the concerns started to give way to a slight case of stage fright. Equipped with a well thought-out concept for his first "own" TRIZ-Workshop Hans was optimistically travelling back home. Also, he passed the test with very good results! He was proud and celebrated his success with a big cone of ice-cream, which reminded him a bit of his time in the university.

The next Monday, back at his desk, he thought about how to integrate TRIZ with his usual way of working. He simply didn't want to fall back to the old routine! "*I'll take my time to sort it out while going over my to-do list. I'll make a plan, which TRIZ tools I could use for which tasks.*" he thought. He retreated to a small meeting room called "Thinking Island" – this new room concept the organizational developers came up with is not so bad after all - he smirked. On the whiteboard he started to gathered all contradictions that he could recognize in the tasks and projects he was involved with and developed his "TRIZ-ified" approach to his work.

Despite little banters from his colleagues in the beginning, Hans succeeded to establish little TRIZ sessions whenever they faced tough problems. The systematic approach and successes they achieved intrigued his colleagues, they quickly wanted to know more. Happy about this reception, Hans felt encouraged and satisfied and eagerly set off to work on the next problem.

2. Hero's Journeys for Skills Development

2.1 Developing personality through a Hero's Journey

The story above shows that Hans was not satisfied with his work situation because of the pressure, lack of ideas and better competitors. He wanted to change something. Despite his first hesitation and because of the increasing market pressure, he finally gathered all his courage and asked for the budget for the training. With this step he took the first hurdle, overcame his self-doubts and stepped into the unknown land of the "TRIZ Adventure". During the training there were several tests and trials: Changing the way of thinking is a tough challenge, as well as mastering the amount of new knowledge, and finally the written test. In the end he is not only encouraged by the new possibilities, ideas and suggestions he gets, but also his self-confidence increases because he succeeded in the written test where he could proof that he was able to correctly apply the tools he learned and that he understood the correlations.

The preceding research and gathered arguments for requesting the training budget as well as the planning of the transfer of the new know-how into the daily routine are the "Mentors", helping on and strengthening courage and self-confidence. The experience gathered through the training, the exchange with his "ally", the other training participants, and the validation through the certification test all made him confident that he would find good solutions later on. This confidence finally convinced his colleagues, which witnessed a "new" Hans that was excited to face new problems and work out inventive solutions systematically, instead of whining about the tough situation and pressure of ongoing change. Hans had the courage to change his old habits, testing out his new methods, going through failures and mistakes, steadily improving himself. The implementation of his new knowledge is successful because of the hardship and experience he went through on his Hero's Journey.

The following figure shows this particular journey with the 12 steps, see Fig. 1:

Fig. 1 The Hero's Journey, shown by the situation of Hans, a TRIZ student

New solutions grow out of experiments with the unknown. Consequently, new solutions are to be found in the unknown. [5] On his way the hero has to be able to change and proof his flexibility in different roles that he has to play. By reflecting his own experiences, the hero gets aware of his ability to grow despite of, or even because of, all insecurities, challenges and imponderabilities he had to face. He increasingly gets aware of the changing roles and relationships. The example of Hans shows, that the protagonist himself grew to be the designer and driver of change.

When compared, the Hero's Journey and the typical experiences of a TRIZ-beginner show clear similarities. The Hero's Journey can be seen as a strategy to approach one's own way to become a "TRIZ problem solver" and actively facing the coming (organizational and psychological) obstacles.

As a topic for further analysis, analogies between Campbell's "Hero's Journey" and Altshuller's "Life Strategy of Creative Personality" [10] could be assessed – first observations indicate several possible similarities.

2.2 Developing Organizations with the Hero's Journey

The experiences of Hans described above can also be transferred to teams, departments and organizations. His story illustrates that heroes are not born, but are made out of ordinary people. Everybody can be a hero. When we get invited to witness a story together with the protagonist, to act and to suffer together with him, the story gains affective intensity that makes us dive into the story and keeps us inside of it. [8]

In the shape of a Hero's Journey a change process of an organization becomes a story which not only speaks to the mind, but as well to the hearts and emotions of the people involved. A story touches and creates affective impact, if it is developed, thought through, told and experienced by all people involved. [7] Telling a story helps all participants to reduce the complexity of upcoming change to discrete pictures and increasing the amount of knowledge and experience. Ideas can be stated more courageously and spoken out loud because of the pictorial, eventful and associative communication related to a story. The sensed experience is triggered deeply, challenges get catchier. The connection of heart and mind speaks to humans holistically.

As the Hero's Journey also considers doubts and mistakes that have to be corrected, the human being is accepted with all his benefits and shortcomings. This acceptance makes it easier for the participants to speak their mind freely, admit mistakes, asking for help and participating in a collective working rhythm that can lead to a state of Flow.

The abstraction in form of a story also makes it easier to question the status quo. Especially this is one of the hardest challenges for many people: Admitting, that previous activities have been good, but is not sufficient or even debilitating for future challenges – without knowing how future activities might be successful or how they should look like. [8]

Insofar the dramaturgical development of the Hero's Journey does not only reflect the transformation of personal change and development, it can also be used as a synonym to describe change or innovation processes of companies.

"All story texts have the basic ability to create models of reality […] They do not depict reality, they design realities." [7] Within this context it is insignificant if the stories have a lot or little to do with the daily life of the readers or listeners. In fact, it is more crucial that the stories have the ability to enable humans to create whole concepts of reality within their mind. "By this, they relate to the knowledge of the recipients and build on more abstract layers of knowledge than the pure knowledge of "normal" daily life: They utilize the ability of the viewer or listener to envision a "possible" daily life with all of its normative deep layers." [7]

3. Conclusion: The Hero's Journey as strategy for learning and using TRIZ

This paper shows that the concept of the Hero's Journey can be used as an applicable, emotionalizing analogy to learning and implementing the TRIZ methodology. The activated inner relationship supports human beings to accept their doubts and constraints and to actively deal with them. They touch the unconscious which also helps to create new solutions need for their work. The tension-laden storyline of the Hero's Journey on the one hand activates intrinsic motivation to "persist", on the other hand it strengthens their self-confidence due to the mastered challenges.

Both aspects "intrinsic motivation" and "increased self-confidence" are crucial support factors for learning and implementing TRIZ as well as for finding of new and creative solutions.

Based on these observations the authors draw the conclusion that it is not so important to simplify TRIZ so it gets learned and applied, rather it is about communicating the Hero's Journey of TRIZ users on an emotional level to inspire potential users for this methodology.

Annotation

TRIZ Master Valeri Souchkov adverted, that The Hero's Journey is comparable with Altshullers' live story and his recommendation for TRIZ students, which is described e.g. in the book "How to become a Genius?" [10].

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THE LAW OF SUPERSYSTEM COMPLETENESS

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Abstract

The paper introduces the Law of Supersystem Completeness and explains reasons of why it was proposed. This law belongs to the category of Laws of Static originally developed by the founder of TRIZ G. Altshuller. Main purpose of introducing the law is to provide formal background for further development of criteria which would help to identify potential mismatch between a technical system and its supersystem due to unavailability or immaturity of supersystem components which are required to ensure not only successful operation of a technical system and proper execution of its functions but its success on the market as well. The paper is illustrated by the examples.

Keywords: TRIZ Laws, Technology Development, Law of Supersystem Completeness,.

1. Introduction

The System of Laws of Technical Systems Evolution was introduced by G. Altshuller in 1979 [1]. The original system consisted of 8 laws divided to three groups:

- **The Laws of Static** which define conditions for a technical system emergence, composition and viability.
- **The Laws of Kinematic** which are observed independently from specific technological and physical factors which produce impact on evolution of a technical system.
- **The Laws of Dynamic** which imply that evolution of every technical system depends on specific technological and physical factors which produce impact on evolution of a technical system.

Afterwards, the system has been revised and updated by a number of TRIZ co-developers and TRIZ schools, some laws were redefined, new lines of evolution (also known as trends and lines of technical systems evolution) were proposed. These updates resulted in several systems of TRIZ Laws and Trends of Technical Systems Evolution known today [2,3,4,5]. New trends of evolution were suggested, like in [6] and are introduced by TRIZ authors today [7]. Later the term "Law" for certain laws defined by G. Altshuller was replaced by some TRIZ authors with the term "Trends of Technical Systems Evolution" due to the lack of exact statistical proof that the these laws are valid for all technical systems under certain circumstances without exception. All these facts indicate that research on the Laws and Trends of Technical Evolution are still in the developing state and the system is far from being complete.

2. Current Situation

2.1. Definition of Supersystem

According to the most important law of TRIZ – the Law of Technical System Completeness which belongs to the category of Laws of Static, a minimally viable technical system includes at least four components (subsystems) which provide functions of 1) Engine, which is fed by energy received from supersystem (energy source), 2) Transmission, 3) Control Unit, and 4) Working Unit which delivers main useful function with respect to a certain target, which is also known as "product" in Classical TRIZ (Fig. 1). Both Energy Source and Target belong to supersystem.

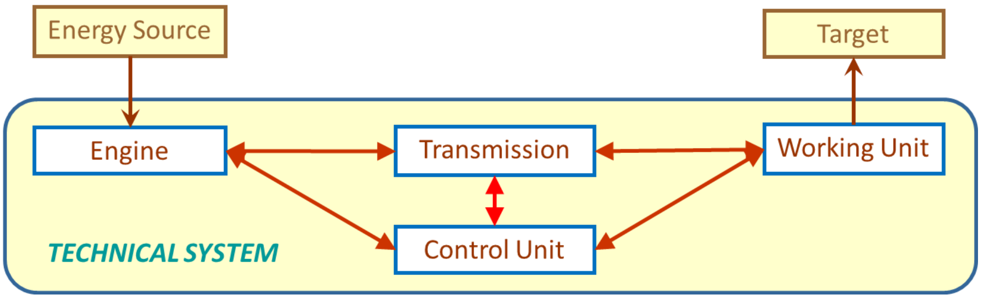

Fig. 1. A Complete Technical System

If we look carefully at the most of the systems of the Laws of Technical Systems Evolution (Development) we can notice that all the laws and trends relate to either technical system or to its particular subsystems. However it is obvious that a technical system does not exist for itself. Every technical system delivering a specific main function is created with a certain purpose to be utilized by its higher system, which is known in TRIZ as a "supersystem".

In TRIZ, supersystem is defined as "*A system that includes a technical system given as its part (sub-system)*." [8]

However, each system has its own lifecycle which demands different supersystems for the same system at each phase of its lifecycle. For example, during delivery of a new digital photo camera to a customer, the camera is stored in a package. Is the package a part of supersystem of the camera? Classical TRIZ usually considers supersystem only within the context of a time frame when a technical system is in operational mode. Nevertheless, without focusing on each phase of the technical system lifecycle, the system will not be able to work as and where required.

Therefore, supersystem of the camera during its transportation and delivery has the high degree of importance as well. The package will be a part of supersystem since it interacts with the camera at a particular stage of the TV set lifecycle and delivers useful purpose – protects the camera from damage during transportation.

In other words, we can expand the definition of a supersystem and define it as "*a system which interacts (through physical or informational links) with a technical system at each phase of the technical system's lifecycle*".

2.2. Complete Technical System is Not Enough

Just creating a complete technical system that would include all abovementioned four components which properly deliver their functions does not mean yet that the system will work as expected. Such a system exists inside its supersystem, and it is crucial that its supersystem also possesses the minimal number of ingredients necessary to provide proper functionality of the technical system at all stages of its planned lifecycle. According to [9], each year more than 30,000 new consumer products are launched and 80 percent of them fail. There is a number of reasons why products fail on the market, and one of them is mismatch between a product and its supersystem.

One of the most known historic cases of mismatch between a technical system and its supersystem is invention of the mass car production by H. Ford. Before his famous *Ford Model T* car, only rich people could afford a very expensive custom-built car. A number of Ford's innovations in the car design and the assembly line made it possible to produce a car available to people with average income. By 1914, his plants were producing 260.000 cars annually. But there was one big challenge: the roads which existed at that time in the U.S. were not built for cars, most of them were not paved. It meant that producing a large volume of cars could meet serious barriers. One of the solutions in *Model T* was to use strong and light vanadium steel for critical parts thus making the car very durable on rough roads. But the other solution was success of convincing government to increase rate of building paved roads which was a necessary ingredient of the car's supersystem. Further attraction of investors and introduction of gasoline tax part of which was used for building new roads helped to drastically increase the number of paved roads in the country which, in turn, increased cars production and sales [10].

Another case is evolution of digital music players. Before Apple announced its famous *iPod* in 2001, there were other digital music players on the market, produced by some major brands including Sony. However, their sales were rather slow: one of the reasons was that legal music files were hardly available on the Internet rising a simple question: "*Where to get music?*" *iPod* disrupted the market by producing a solution in supersystem: Apple linked *iPod* with *iTunes* online web store where everyone could purchase separate music files from a very large collection without the necessity to purchase expensive full albums [11]. As a result, by the end of 2002 *iPod* captured 82% of the U.S. retail market share.

The examples above illustrate the immaturity of supersystems with respect to system's targets and use. Often, a technical system fails due to immaturity of supersystem providing energy source. Attempts to widely distribute transistor radios in African rural areas in the 1970th failed due to the lack of electricity supply networks and high price of batteries.

There are plenty of examples in the history of technology demonstrating how ignorance of availability or immaturity of supersystem components led to failure of new innovative products which either arrived too early on the market or failed due to a lack of one of the critical supersystem components.

Thus the question emerge: how can this ignorance be avoided? Partly, building Technology and Product Business Roadmaps [12] helps with answering this question. However there is no formal background for systematic assessment of supersystem which can be used to identify potential mismatches.

Therefore the author's opinion and proposal is to expand the Laws of Static with one more law: The Law of System Completeness which describes conditions necessary for a technical system to be functional, viable and adding value in the outer world.

3. The Law of Supersystem Completeness

3.1. Definition

As becomes clear, The Laws of Static can be expanded with one more law: The Law of Supersystem Completeness. The definition of the Law is as follows:

> *For successful and sustainable delivery of functionality, providing required performance and quality, and staying viable, a technical system (TS) should possess a supersystem which consists of at least four components:*
>
> 1. *Supersystem providing TS' energy source.*
> 2. *Supersystem providing TS lifecycle.*
> 3. *Supersystem providing TS control.*
> 4. *Supersystem of TS' target.*

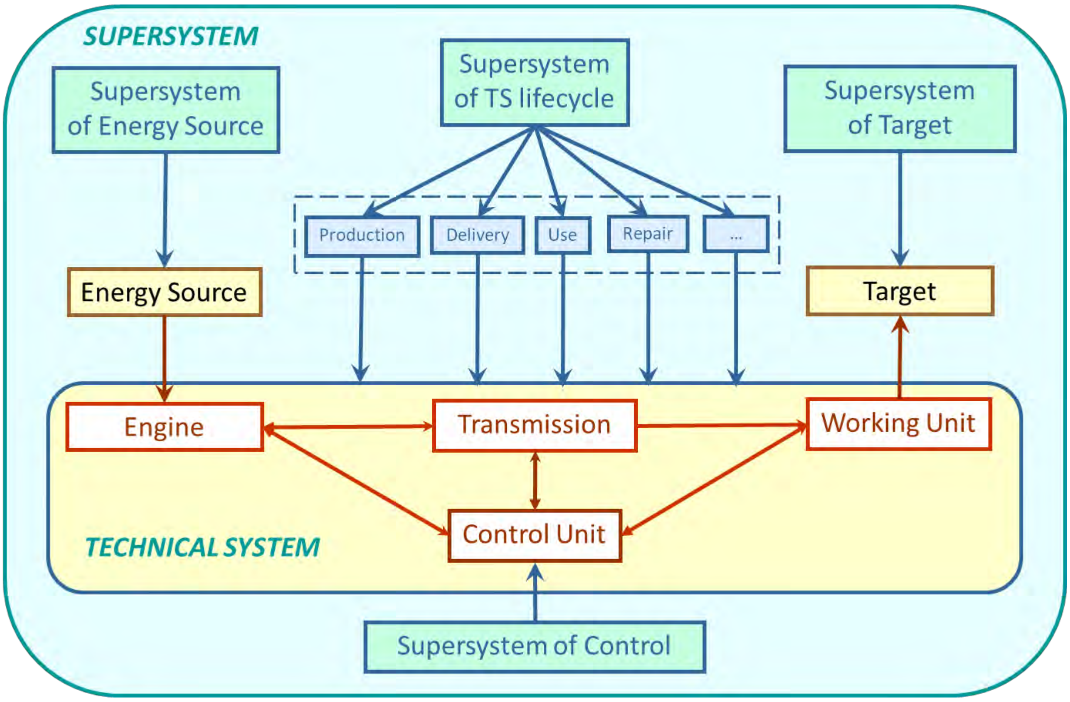

Fig. 2. The Law of Supersystem Completeness

3.2. Explaining Key Components

As seen, the completeness of supersystem is defined by four key components (Fig. 2):

1. **Supersystem providing Energy Source:** every component of a supersystem which is needed to provide, supply and deliver energy necessary to ensure expected TS functionality (including its different parts). Electric home appliances will be useful unless electric current is provided by the city grid or by a standalone diesel generator which, in turn require diesel fuel. Electric *Tesla* cars would not run unless there are charging stations at homes and parking places. Thus the supersystem of Energy Source must ensure that energy needed to feed a technical system and its parts is always available and delivered to the system as long as it is needed.

2. **Supersystem providing TS Lifecycle:** everything which is needed to provide different phases of TS Lifecycle. Most critical among them are:

   - *Production*: Minimal number of subsystems of a supersystem which is needed to enable manufacturing and distribution of TS: R&D; design, manufacturing facilities and HR; supply chain of parts; marketing and sales channels, logistic operations, etc.
   - *Delivery*: Minimal number of subsystems required to deliver a system to its operation location unless the system will be operated exactly at the same place where it was built.
   - *Use*: Minimal number of subsystems of a supersystem which is needed to use a TS. Includes support, maintenance, production and delivery of parts and consumables needed for TS to operate, etc.
   - *Repair*: Minimal number of subsystems of a supersystem which are necessary to repair the technical system.
   - *Utilization*: Minimal number of subsystems of a supersystem related to utilization of a system or its second-hand use.

   These five parts of supersystem needed to provided technical system lifecycle mentioned above are most critical parts. There might be more parts involved depending on a specific technical system.

3. **Supersystem providing TS Control**: Minimal number of subsystems of a supersystem which provide control over a TS. It can be both human-based and automated. For example, a human driver is needed to drive an ordinary car, but GPS and traffic monitoring systems can be used to control an autonomous car.
4. **Supersystem of TS Target**: Minimal number of subsystems of a supersystem which is needed to enable supply, processing, creating and use of a target (product) of a technical system. This supersystem is different from the supersystem required for the use of technical system because it relates to the technical systems only partly, instead it focuses on supersystem of target of the technical system. For example, it might be not wise to try to distribute perfectly working coffee machines in areas where people do not drink coffee at all. Another part of such a supersystem are components which must interact with a technical system to enable the full use of its purpose. For example, in the above mentioned case with *iPod*, supersystem provided music files to enable effective use of the digital music player. Supersystem of TS' target also includes those target's parts which might be needed for production (change, preservation) of the target but which are not parts of a technical system, like a mill to grind coffee beans before coffee powder can be placed to the coffee machine.

It is important to note that certain components of supersystem might belong to several categories depending on their particular purposes and involvement. For example, a person can be considered as a part of supersystem of TS control and supersystem of TS's target: first, the person controls the coffee machine to prepare the required type of coffee drink, and then consumes the prepared drink.

In addition, today we observe a trend of technical systems becoming components of so-called product "ecosystems" which integrate various technical systems on the basis of technology platforms to enable effective use of their targets. For example, a photo taken by a digital camera can be instantly transferred to a digital cloud or shared to smartphones of friends without participation of a user.

3.3. Example

In the example below, the minimal number of necessary components of supersystem for an ink-jet computer printer are presented.

1. **Supersystem of Energy Source (electricity):**
    - Functioning electrical grid
    - Electrical power supply
    - Electrical connections in a house/office
    - Connecting cable
2. **Supersystem of TS Lifecycle (printer):**
    - Production
        - Printer manufacturing facilities
        - Supply chain of parts for printer manufacturing
        - Sales and delivery channels
    - Use
        - Electronic device (connected to the printer)
        - Electronic file with printing data
        - Internal driver software
        - Connection cable
        - Electricity supply converter
    - Repair
        - Repair facility
        - Spare parts
        - Technical specialist
    - Utilization
        - Waste collection
        - Used cartridges processing
3. **Supersystem of Control:**
    - A person (user)
    - External printer control software
    - Computer
4. **Supersystem of Target (printed text and image):**
    - User

- Printer paper
- Printer paper delivery channel
- Cartridges with ink
- Cartridges with ink delivery channel
- Customer support

4. Practical Use

During practical activities, the author often meets with start-up founders who propose new products to create Blue Oceans, or with investors who are interested in evaluating potential of new disruptive products and technologies suggested by inventors at both small and large companies. It might sound surprising but it is a fact that little attention is paid to the assessment if a supersystem which will provide the TS lifecycle, its energy source, and the most effective use of its target is ready and mature enough. However such assessment is crucial to ensure success of new products on the market.

5. Conclusions

The issues of correct definition of availability and maturity of supersystem parts that are critical for successful production, operation and maintenance of technical systems are important for timely identification of potential failures of new innovative products and technologies. Therefore assessment of such critical parts is needed.

The Law of Supersystem Completeness formulated in the paper may serve as a basis for designing a set of criteria which must be met for each new innovation. Such criteria can be used, for example, first, for evaluation of the degree of potential of success of new products and technologies, and second, as a part of Product and Technology Business Roadmaps which are developed to plan future innovative development of existing products and technologies.

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THE IDENTIFICATION OF CONTRADICTIONS IN CLIFF: AN AUTOMATIZED ZIPPER PROTOTYPE USING THE TRIZ METHOD WITH ROOT CONFLICT ANALYSIS (RCA+)

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Abstract

This paper presents preliminary results of our efforts performing the TRIZ method with Root Conflict Analysis (RCA+) to solve a particular issue related to the Cliff prototype. The Cliff is an automatized zipper project which designed to overcome the struggle faced by elderly, people with physical impairment, and ladies who have difficulties zipping the back-zipper dress. Cliff got stuck during its movement while moving on the jacket to automatically complete the zipping or unzipping processes. Engineering or design problems need to be analyzed systematically and scientifically to find the useful solution. Therefore, the TRIZ with the use of RCA+ method has been chosen to identify potential solution to solve the automatized zipper prototype problem. This method helps to graphically map all the causes and effects contributed to the traction problem of this automatized zipper which is summarized by the seven contradictions identified. The technical contradictions then are resolved using the TRIZ method based on the utilization of the Altshuller matrix. From the Altshuller matrix, 26 inventive principles are triggered as the potential solutions. After screening all the 26 principles, only 12 principles are suitable with the problems faced by the automatized zipper. The most promising inventive principles triggered are the segmentation, taking out, asymmetry, spheroidality-curvature, and replace the mechanical system. However, potential solutions such as hydraulics and thermal expansion are in conflict with strict safety and product semantics. From the analysis, we found that the TRIZ method with RCA+ is very useful to systematically approach the design problem of the automatized zipper. Further brainstorming will be conducted to improve the current prototype of the Cliff.

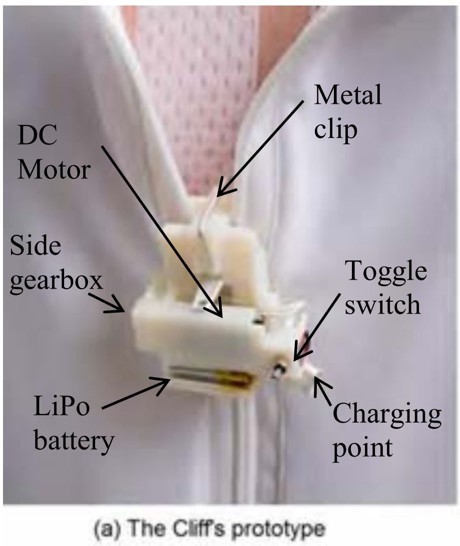
Keywords: TRIZ, RCA+, automatized zipper, miniaturization.

1. Introduction

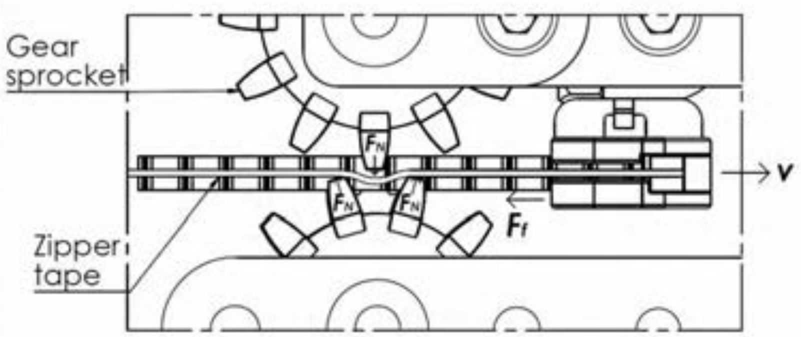
A systematic and scientific approach are essential in analyzing any kind of engineering or design problems. It is important in order to trigger useful potential solution for the problems. The TRIZ method is one of the well-known problem solving technique [1-4]. TRIZ is a Russian acronym which can be expressed in English as 'Theory for the Solution of Inventive Problems'. This method consists of a theory, operating procedures and a range of tools created by Genrich Saulovich Altshuller. Since 1946, the objective of TRIZ is to capture the creative process in technical and technological contexts, classifying it and making it repeatable and applicable. TRIZ is also described as a proper theory of invention [1]. The systematic working methodology of TRIZ is based on a series of subsequent stages and operating tools to perform the analysis, the structuring of models, and ended with the solution of problems. Up to today, the TRIZ methodology has proved to be the most efficient to solve inventive problems and one which may be easily learned and used without any need for an extraordinary individual creativity [1-3].

The other problem solving techniques are the Six Sigma, the Taguchi method, Quality Function Deployment (QFD), brainstorming, and synectics and the use of analogies. Comparing these methods to TRIZ will bring us to look in overall suitability of the particular method towards our design problem. The TRIZ's extensive database is the key of the successful creative design process which is offered by TRIZ [4,5]. The database allows us to take advantage of knowledge from thousands of the world's patents. Besides that, TRIZ also assist in making the prediction about the future changes which can be made on the product or the features that a new product should have [8]. The variety of analysis tools available in TRIZ for different purposes makes it one of the favourites toolkits used by the engineers and designers to understand and solve their problems. The TRIZ tools will navigate us to find all the feasible ideas or ways to improve or solve the problems [1]. Besides that, TRIZ also helps us to stimulate new ideas, creative thought, and innovative solutions. Therefore, TRIZ with the use of Root Conflict Analysis (RCA+) has been chosen to deal with one of the problems faced by the Cliff, an automatized zipper. The RCA+ is one of the TRIZ's tools which is used to investigate the underlying causes.

The Cliff is a project intended to develop an automatized zipper in response to the struggle by elderly, people with physical disability and ladies who have problems zipping the back-zipper dress [9,10]. Showing in Fig. **6**(a) and Fig. **6**(b) are the Cliff's prototype and the diagram of its traction mechanism, respectively. Cliff's used two gear sprocket wheels as traction mechanism on both sides of the tape to establish the uniform distribution of normal force acting towards the zipper tape. The problem is regarding the movement of the automatized zipper prototype during its operation. The Cliff's prototype stuck while moving on the jacket to automatically zipping or unzipping it.



(a) The Cliff's prototype



(b) The Cliff's traction mechanism

Fig. 6

2. Root Conflict Analysis (RCA+)

Root Conflict Analysis (RCA+) is one of the new addition to the TRIZ tools and technique family [11]. RCA+ can be used to investigate the underlying causes and their interdependencies for an observed effect which can be visualized in a graphical way. Several alternative known methods are Ishikawa diagram (Fishbone diagrams), Root Cause Analysis, Method of five "why's", and the Current Reality Trees in Theory of Constraints [12]. The common drawbacks of these mentioned methods is that they do help in finding the problems but the methods do not provide means to solve problems.

The RCA+ was developed based on three methodologies which are the cause-effects chains, the theory of constraints, and the TRIZ itself [11]. The modelling of the RCA+ is performed within the scope of three tasks; (1) to solve a particular problem related to an individual specific product, service or process, (2) to solve a broad problem related to a whole class of products, processes or services, and (3) to predict and eliminate possible failures within system and processes [11]. The principle of this method is to map all causal chains of causes and effects devoted to a problem, which is represented as a general negative effect. Then, RCA+ will identify the conflicts which can further be resolved using TRIZ. In order to construct the RCA+ diagrams, this method require our effort to keep asking *"what causes this effect to occur"*. By doing this, we may find all the reasons contibuting to the negative effect.

2.1. TRIZ Process with RCA+

Showing in Fig. 7 is the overall process flow of problem solving based on using the Root Conflict Analysis in TRIZ [11]. This technique used for defining and selecting the contradictions in the problem study. The contradiction is defined as "a situation when the same cause causes both positive and adverse effects" [1, 8]. For this study, only the RCA+ will be performed and not the Value-Conflict Mapping. The Value-Conflict Mapping is designed to help with extracting and linking technological, business and market contradictions which are not related to the technical problem of this study [13].

This study uses RCA+ to identify and select the contradictions, and then will be divided into two flows. The first flow is based on the application of basic TRIZ tools which comprises of the Altshuller Matrix and the 40 Inventive Principles. An engineering contradiction is a condition in which an attempt to improve one parameter of a system leads to the worsening (impairment) of another parameter [1]. It can be reflected in a positive and negative interaction between two or more components. By using the contradiction matrix, we can see which of the 40 inventive principles are relevant to our problem. The 40 Inventive principles is a basic generalized rule that is accepted as facts, works in the same way consistently and usually followed as a basis of reasoning or explanation of the invention. Altshuller screened 200,000 patents to find out what kind of contradictions were resolved by each invention and the way it was achieved. He synthesized down to 40,000 patents, and then he developed a set of the 40 inventive principles [14]. Finally, from the potential solutions given by the matrix, we need to use our brain to make it a useful one. It is then the task of problem solvers to make use of these TRIZ solutions triggered to find fruitful and detailed solutions to each of their problems. The second flow will take place if the problem is not solved using the application of Altshuller matrix. The process will be continued using the advanced TRIZ tools such as ARIZ (Algorithm of Inventive Problem Solving), Inventive Standards, Separation Principles, and so forth. The selection of flow also depends on the degree of TRIZ expertise of the problem solver [11].

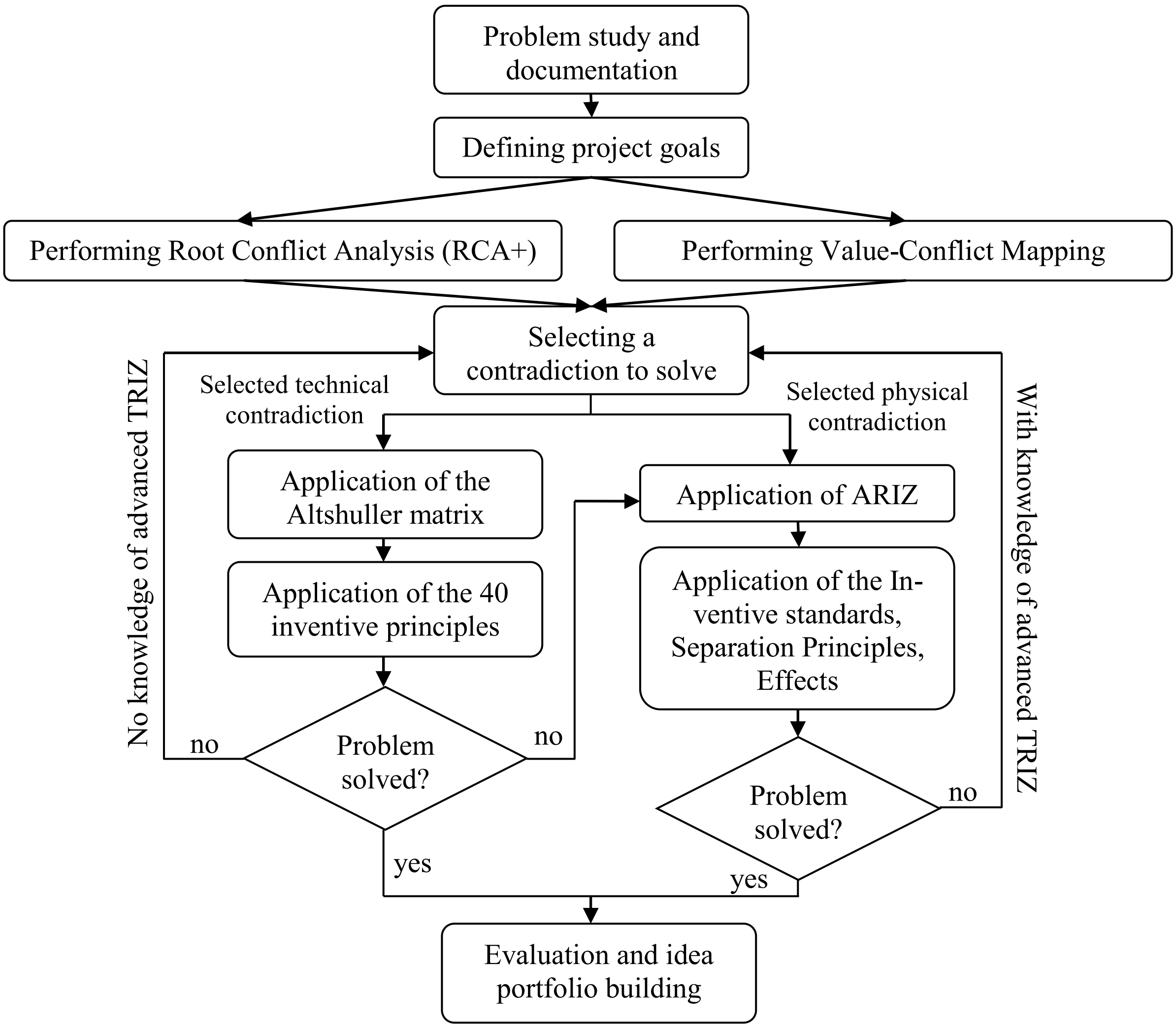


Fig. 7. The Overall TRIZ Process with RCA+ [11]

2.2. Modelling and building the RCA+ Diagram

Showing in Fig. 8 and Fig. 9 are the RCA+ diagram for the negative effect which is specified as "the Cliff did not move (stuck) on the fabrics". This diagram has been drawn in a top-down manner by keep asking "what causes this effect to occur?" during the problem mapping process. There are four types of causes/effects in an RCA+ diagram. The Negative (-) are the causes/effects which is entirely negative and we would like to eliminate it. The second one is the Positive (+) effect, which is there is no need to change. The Combined Negative and Positive (+/-) is the same cause results in both positive and adverse effects. Lastly, the Non-Changeable (--) is the cause contributes negatively but can not be eliminated, or modified since it is beyond our control within a given problem scope.

As can be seen from both Fig. 8 and Fig. 9, there are seven contradictions identified which will be discussed in the following section. The contradiction is defined as a situation when the same cause causes both positive and negative effects. The Non-changeable causes (NC) won't be analyzed further since it is beyond our control.

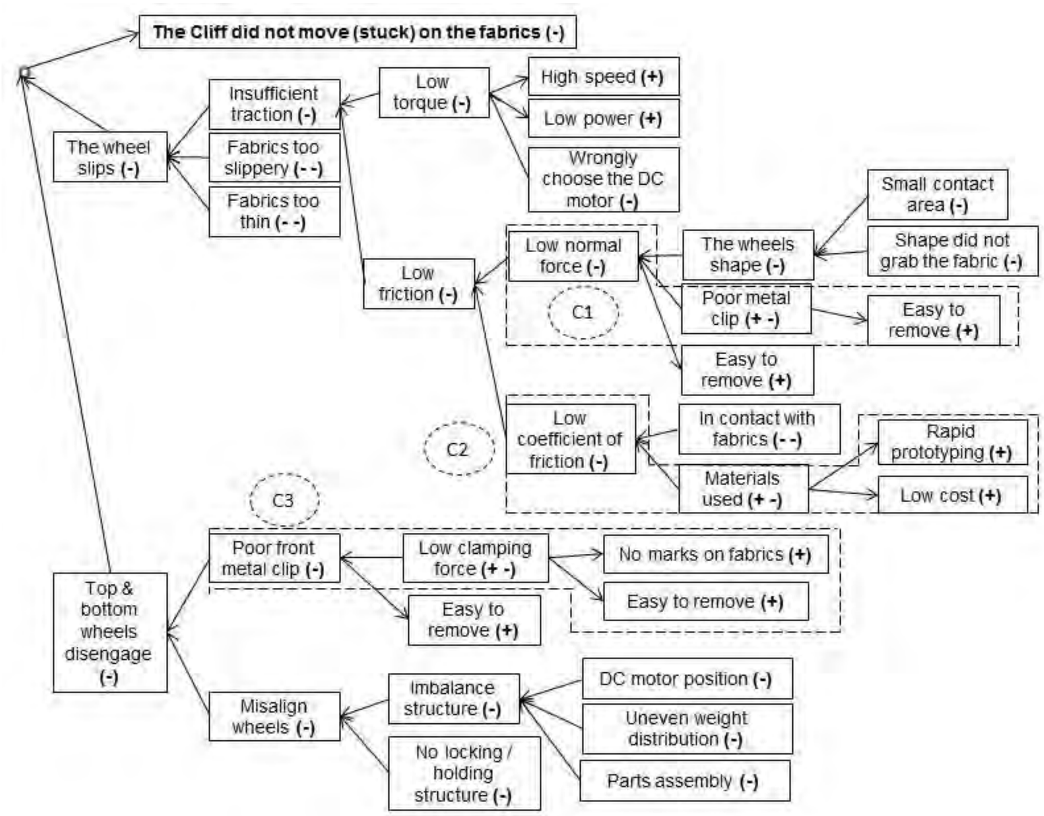


Fig. 8. RCA+ diagram (Part 1)

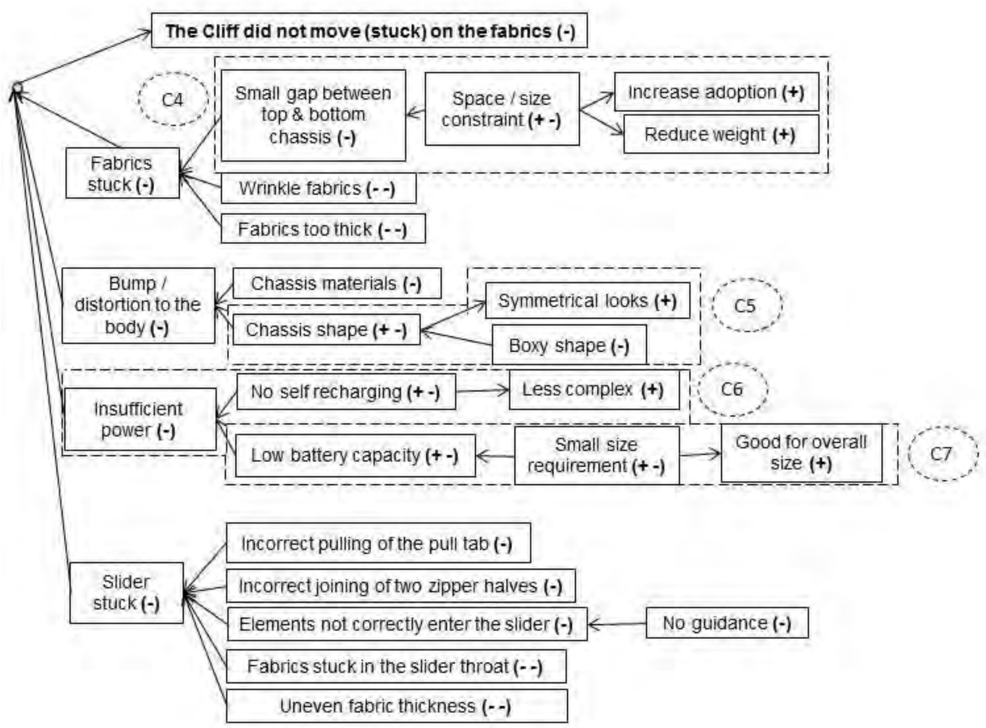


Fig. 9. RCA+ diagram (Part 2)

3. The Contradictions Discussion

3.1. Technical Contradictions and the Source of the Physical Contradiction

The Technical Contradiction defined as "*formed by a couple of negative effect vs. positive effect*" [11]. These two effects can be directly matched against positive and negative parameters in the contradiction matrix (Altshuller Matrix). Meanwhile, the source of physical contradiction is described as "*two opposite states of a cause which is a source of the physical contradiction. One state of the cause should provide a positive effect whereas its state should be opposite at the same time to avoid the appearance of a negative effect*" [11]. Such contradictions can be solved either with Principles for Physical Conflict Separation or ARIZ. Listed below are the technical contradictions identified:

C1: *"The metal clip should be strong to provide a sufficiently large normal force to avoid the wheels slips, and not too large force to make it easy to be removed".*

C2: *"The material used as the wheels need a high coefficient of friction to avoid the wheels slips, and not too costly & time-consuming to manufacture it".*

C3: *"The low clamping force is not right for the front clip, but it will make the device to be easily removed and leave no marks or damage the fabrics".*

C4: *"The space/size constraint could increase the adoption of this device and reduce the weight, but it could produce a small gap between the chassis and the fabrics which could cause the fabrics to stuck in between".*

C5: *"Poor design of the chassis shape could produce bump/distortion to the human body, and at the same time provide the symmetrical looks to the Cliff".*

C6: *"Without self-recharging function, it will reduce the system complexity, but might lead to insufficient power problem".*

C7: *"The small size requirement is perfect for the overall size, and at the same time smaller battery might result in low battery capacity and insufficient power problem"*

3.2. The negative causes

There are few negative causes without an underlying contradiction identified, which we will try to solve the problem by eliminating the cause. Firstly, the misalign wheels problem contains set of negative causes only. It is possible to solve it by eliminating the causes which are the imbalance structure and no locking/holding structure. Therefore, the parts assembly need to be improved to ensure weight distributed evenly on the structure. Secondly, the slider stuck problem involves few negative causes. The causes are incorrect pulling of the pull tab (caused by the stopper beneath of the bail), the incorrect joining of the two zipper halves, and the elements did not correctly enter the slider which is happened because of no guidance. Therefore, the next design iteration will consider to include the guider, to ensure the elements correctly enter the slider throat.

4. Contradiction Selection

Table 1

Summary of the Technical Contradictions for selection

	Cause	Positive Effect	Negative Effect	Part(s)	Property / Parameter	Time of Conflict
C1	Poor metal clip	Easy to remove	Low normal force	Front metal clip	Normal force, clamping effect	During the operation
C2	Material used (wheels)	Low cost, rapid prototyping	Low coefficient of friction	Rotating wheels	Coefficient of friction	During the operation
C3	Low clamping force	Easy to remove, no marks / damage to fabrics	Poor metal clip	Front metal clip	Clamping force, normal force	During the operation
C4	Space/size constraint	Increase adoption, reduce weight	Small gap between chassis & fabrics (increase resistance)	Wheels, top & bottom chassis	Size, space, weight, resistance	When moving on thick fabrics
C5	Chassis shape	Symmetrical looks	Bump / distortion to the body	Chassis	Shape, material	During the operation
C6	No self recharging	Reduce complexity	Insufficient power	Battery	Power, recharge method	All the time
C7	Small size requirement	Good overall size	Low battery capacity	Battery	Overall size	All the time

The process continues with the contradiction selection.

Table *1* summarized the summary of the technical contradictions for selection purpose. These selection criteria are performed by listing its cause, positive effect, the parts involved in the contradiction, property (parameter) which forms a physical contradiction, and time when it occurs. As we can see, there are few contradictions which are related to each other. The first one is C1 and C3 which is regarding the front metal clip. This part is an essential component in the prototype which provides the normal force or clamping effect to ensure the rotating wheels is in contact with the fabrics to produce traction. Besides that, the metal clip also allows the automatized zipper to be easily removed from the jacket. Secondly, C4 and C7 contradictions are all about the overall size of the automatized zipper. The size limitations will lead to a small gap between top and bottom chassis (which thick fabrics can get caught in between) and also a tough challenge to select tiny electronic parts such as the battery, switch, etc. In another dimension, if we manage to overcome this problem, it can increase the adoption of this device among the users and reduce its total weight.

The second contradiction (C2) deals with the materials used for the rotating wheels. Using the rapid prototyping material (plastic) bring benefits regarding the cost and save time for prototyping cycle. In the other hand, the use of plastic which has a low coefficient of friction will not help to improve the traction of the automatized zipper. Another contradiction which is C5 is about the chassis shape especially the bottom side which has potential to be in contact with the human skin. This situation could produce bump/distortion to the body which might be a negative effect for most of the users. The current shape allowed the Cliff to have a symmetrical look. Lastly, the self-recharging issue (C6) is in line with the concern of insufficient power to the system which could bring a problem to the traction system. Without the self-recharging function, this device complexity is lesser which in turn can reduce the development time. Since few contradictions are related to each other, we now have in total of five contradictions. Therefore, only five contradictions will be selected which are C1+C3, C4+C7, C2, C5 and C6.

For the parameters selection from the Altshuller matrix in the following section, Cliff will be considered as a moving object. TRIZ defines moving objects as an "objects which can easily change position in space, either on their own or as a result of external forces" [1]. The vehicles and devices/products that designed to be portable are the basic members of this class [1].

5. Apply the Alsthuller Matrix Selection

To improve a system which there are two apparently reliant or linked features, one need to be replaced or improved. Improving one parameter/feature might effect another aspect to get worsed. Therefore, the use of the Altshuller Matrix (the contradiction matrix) is to identify potential ways to improve one parameter without deteriorate the others. Based on the contradictions identified previously, Table 2 describes the parameters selection from the Altshuller matrix for each contradiction, and the inventive principles suggested by the matrix. Fig. 10 maps the inventive principles suggested for every contradictions identified.

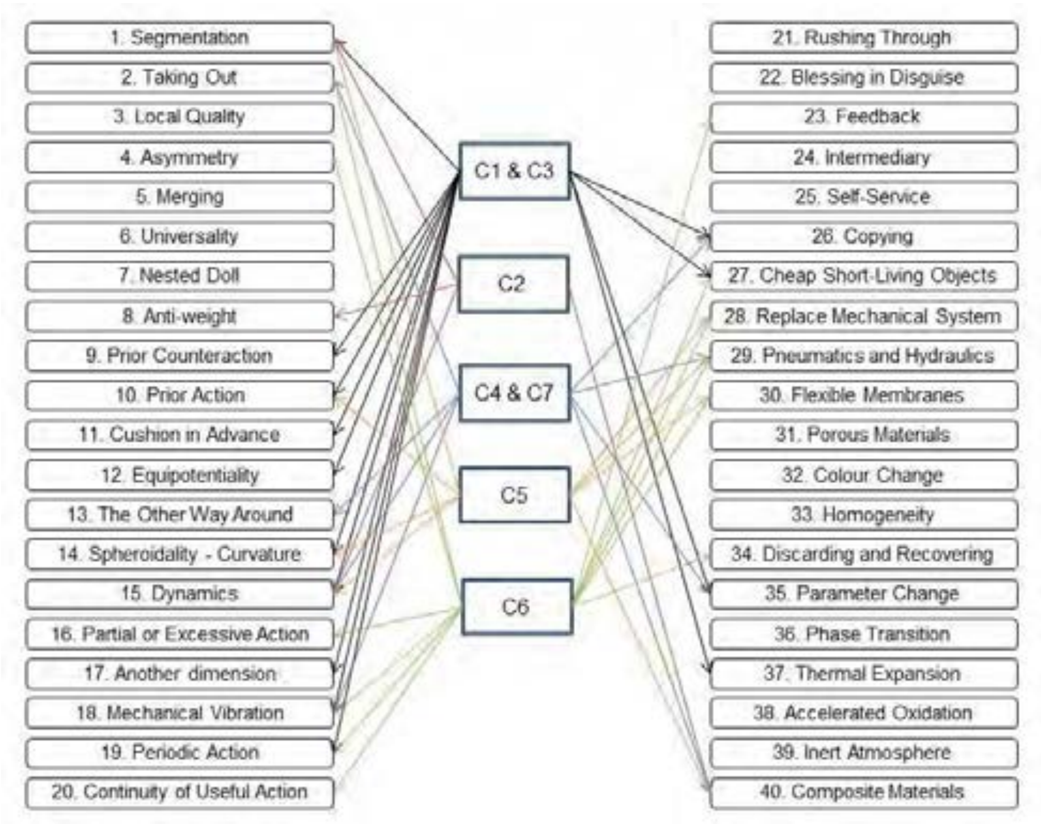


Fig. 10. The mapping of each contradiction with the suggested inventive principles

Table 2

Parameters selection and the inventive principles suggested by the Altshuller Matrix

Contradiction	Contradictions to solve	Inventive Principles
C1 & C3	(10-14): To improve the *force* without worsening the *strength*.	35, 10, 14, 27
	(10-19): To improve the *force* without worsening the *use of energy by a moving object.*	19, 17, 10
	(10-34): To improve the *force* without worsening the *ease of repair.*	15, 1, 11
	(10-7): To improve the *force* without worsening the *volume of a moving object.*	15, 9, 12, 37
	(10-36) : To improve the *force* without worsening the *device complexity.*	26, 35, 10, 18
C2	(14-1) : To improve the *strength* without worsening the *weight of a moving object.*	1, 8, 40, 15
C4 + C7	(7-1): To improve the *volume of a moving object* without worsening the *weight of moving object.*	2, 26, 29,40

	(7-35): To improve the *volume of a moving object* without worsening the *daptability or versatility.* (19-7) : To improve the *use of energy by a moving object* without worsening the *volume of a moving object.*	15, 29 35, 13, 18
C5	(12-35): To improve the *shape* without worsening the *adaptability or versatility.* (12-36): To improve the *shape* without worsening the *device complexity.* (12-14) : To improve the *shape* without worsening the *strength.*	1, 15, 29 16, 29, 1, 28 30, 14, 10, 40
C6	(19-26): To improve the *use of energy by a moving object* without worsening the *quantity of substance/matters.* (19-36): To improve the *use of energy by a moving object* without worsening the *device complexity.* (21-26): To improve the *power* without worsening the *quantity of substance/matters.* (21-36): To improve the *power* without worsening the *device complexity.*	34, 23, 16, 18 2, 29, 27, 28 4, 34, 19 20, 19, 30, 34

6. Results and Discussions

Based on the results obtained in the previous section, the TRIZ analysis using the RCA+ managed to trigger 26 inventive principles as the potential solutions for seven contradictions identified. From the total of the 26 inventive principles triggered, we found that 12 inventive principles have potential to be used in improving the design, while the other 14 principles are not applicable for our design case. Out of the 12 potential inventive principles, 9 of it has a high chance to be further analyzed. The 9 principles are: segmentation, taking out, asymmetry, the other way around, spheroidality-curvature, dynamics, another dimension, copying, and replace the mechanical system. The other 3 which is also to be considered are the cushion in advance, feedback, and composite materials. The other 14 principles that we think are not applicable for our design case are: anti-weight, prior counteraction, prior action, equipotentiality, partial or excessive action, mechanical vibration, periodic action, continuity of useful action, cheap short-living objects, pneumatics and hydraulics, flexible membranes, discarding and recovering, parameter change, and thermal expansion.

Firstly, the segmentation principle triggered us to think about making the Cliff into a sectional object to make it easy to assemble or disassemble it. Secondly, the taking out principle which suggests us to extract or remove the disturbing part is also useful to improve the traction problem of the automatized zipper by removing the side gearbox from the fourth iteration prototype.

It is also in conjunction with another principle triggered which is to replace the mechanical system with the magnetic system. Using the attraction force between two magnets could be another option to replace the front metal clip to provide the normal force for the clamping function. The asymmetry and the other way around principle will lead us to think about changing the view of making a symmetrical design to an asymmetrical one, and also to looks for improvement from the other side or angle. For instance, moving the front metal clip to the other side of the chassis with the same intention which is to provide the normal force for clamping purpose. The next potential principles to be applied is the spheroidality-curvature. The current boxy looks of the Cliff can be changed to a smoother and curvature shape along the top and bottom chassis. By doing this, it can reduce the sharp edge and improve the looks of the Cliff itself.

The use of TRIZ during the iterative research through design process has shown that this method is very useful. It helps the designer to brainstorm/look for the new ideas or potential ideas. Making prototypes will help the designers to simultaneously discover how to approach any problems in a handy way with close observation. The research through design method encourages the designer to continuously make something (prototype) and reflect to the problems occurred [15]. It might require multiple cycles to achieve the ultimate goals. The perfect solution usually not happen during the first attempt of the design process. The introduction of the TRIZ method in this process offers a lot of potentials especially to systematically and scientifically approach the design problems during the making and reflection stage. TRIZ could assists the brainstorming and exploration process to solve the design problem faced. Hence, it will also reduce the cycle times to develop the next iteration design. Besides that, TRIZ also will brings us to another dimension or different viewing angle to solve a problem.

7. Conclusions

The TRIZ analysis with RCA+ has given a few promising directions to improve the problem of the Cliff: an automatized zipper. Even though we have not decided on the final design of the automatized zipper, the TRIZ method brings us the few potential directions based on the inventive principles triggered such as the segmentation, taking out, asymmetry, substitution the mechanical system with the magnetic system, the other way around, the spheroidality-curvature, dynamics, copying, and another dimension. These potential solutions will be further discussed and applied to improve the current prototype. However, there are also a few potential solutions such as the hydraulics and thermal expansion which will not be considered since those principles are in conflict with strict safety and product semantics. Based on our experience using the TRIZ analysis with RCA+ for this study, we found that TRIZ with RCA+ is useful to be practiced along with the iterative research through design method. It because the TRIZ method will help to systematically organize the making and reflection process during the iterative process itself.

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“TO BEAT THE MARKET”, OR THE ECONOMIC RATIONALE FOR USING TRIZ-BASED INVENTIONS

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Abstract

The present paper presents results of the continued research of TRIZ methodology implementation for the enhancement of business systems' economical indicators, such as Return on Assets (ROA) and Return On Investment (ROI). The previous part of the research was published in TRIZFest 2016 materials under the title “Flow Analysis of Business Systems (Case Study and Theoretical Results)”. In this second part we explain basic ideas more systematically, and check them on additional case studies provided by TIPS practitioners

Keywords: TRIZ, TRIZ, economic efficiency, ROA, ROI, Du Pont model, TRIZ-DuPont model, BCG matrix, economical rationale of invention, portfolio management, "stars" and "cash cows"

1. Introduction

This work continues the research we described in [1]. The general purpose of our research is to give an "economic-style" description of the TRIZ nature, in order to get a tool for unbiased assessment of the efficiency and comparison between the efficacy of TRIZ and other engineering methodologies.

In /1/, we suggested that the well-known DuPont model is used for that purpose, and used our case study to show how it works. In this paper, we describe the way how this model applies to cases of other TRIZ specialists, in order to show that it is generally viable, particularly in project portfolio management.

Above or under this range, the abnormal content size should be formally justified by the corresponding author with a risk of major amendment requested by the reviewers.

2. DuPont model: basics

Let us briefly set forth the basic logic of the DuPont model as we used it in [1]. Here is why we chose it as the basic model: (a) the model concerns all the main business drivers (profit, sales, expenses, assets); (b) the model brings them all together, allowing their overall efficiency and profitability to be seen; (c) the basic indicator of return on assets (ROA) can be used to calculate the return on equities (ROE) and the return on investments (ROI).

We used the following formula as the basic one allowing us to assess business efficiency:

ROA = Profit / Assets, (1)

where ROA is return on assets

Profit is the profit from transactions during a specific period

Assets means the cost of assets that ensured the corresponding profit.

The ROA value can serve as an indicator of business efficiency. If the returns on assets exceed the average market/industry value, then the business is efficient; if not, it is not. The problem about applying this value is that it can easily be calculated post factum based on the performance figures, yet it appears anything but evident which parameters and how to control to make sure it keeps growing, in a pro-active manner, while this is exactly the key target of business development, particularly managerial accounting. For instance, it is evident that such a parameter as Profit cannot be managed directly.

To equip ourselves with a business development toolkit, DuPont8 suggested the following transformation of the (1) formula (dividing and multiplying the source version by the Sales figure):

ROA = Profit/Assets = (Profit/Sales) * (Sales/ Assets) (2)

where Sales refers to company sales volume.

This interpretation of ROA is more instrumental than (1) and contains more "manageable" factors. This evidently implies that, in order to increase business efficiently, one should increase sales profitability and asset turnover. This was actually the economic and managerial innovation of DuPont; it is to be recalled that the system was developed and implemented almost 100 years ago. Today, the approaches to development originating from this logic are evident and widely known.

In [1], we made a new step toward improving the functionality of the (1) and (2) formulae, using the concept of "ideality", one of the basic ones in TRIZ.

The following rearranging logic was used: In general terms, the TRIZ ideality formula is the correlation between the useful functions and the "requital factors", the "expenses" that should be borne to get the required consumer properties.

$$I = \sum F / \sum C \qquad (3)$$

where I stands for "ideality";

$\sum F$, for the useful functions of the product;

$\sum C$, for the sum of "requital factors", the expenses for using the functions.

[8] https://en.wikipedia.org/wiki/DuPont_analysis

Like this, the (3) formula can be seen as an analogue of the Sales/Cost economic indicator in the DuPont formula (2), since in both cases it is essentially about the correlation between useful functions (of products or services the consumer pays the supplier for) and the expenses for getting them (specific types of actions and transactions needed to obtain the monetary equivalent of the useful functions). The difference is that the TRIZ formula of ideality contemplates the "general" expenses and functions (and, accordingly, may refer to specific kinds of expenses, like energy, materials and operations, and specific functions, like duration of use, speed, security, flight altitude, immersion depth), while the (1) and (2) economic formulae represent a financiary view of the same parameters.

Thus, the first hypothesis consisted in the equivalence of the following formulae:

$$I = \sum F / \sum C \sim \text{Sales/Cost} \qquad (4).$$

Then, through simple transformations of the first factor in the DuPont formula,

$$\text{Profit/ Sales} = (\text{Sales} - \text{Cost})/\text{Sales} = 1 - 1/\,(\text{Sales/Cost}) \qquad (5)$$

we get the following:

$$\text{Profit/Sales} = 1 - 1/\,Ip \qquad (6),$$

where Ip = Sales/Cost

the value that we refer to as "product ideality".

It should be noted that the course of "improving" sales profitability and product ideality perfectly coincide, so it can be said that improving product ideality results in better sales profitability. Thereby, we have eventually obtained the first desired correlation between the TRIZ tools and economic models assessing development.

However, it turned out much harder to use the concept of ideality to interpret the second component of the DuPont formula (Sales/Assets), also known as "assets turnover". In fact, Assets in this formula stands for the monetary assessment of either the whole company's possessions (balance sheet), or, more seldom, the cost of the fixed assets.9 Even if we abstract from the monetary value, Assets in physical terms are buildings, constructions, equipment, reserves of raw materials, intangible assets, monetary funds. We had to perform additional research, both in economy and terminology10, to formulate the following hypothesis. In managerial economics, differently from accounting, assets are mainly contemplated as "resource", therefore the Sales/Assets multiplier in the DuPont formula characterizes the "integral efficiency" of a business system as a whole, to-wit, how many useful tools (Sales) have been deployed using the

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[9] We should note that this difference is not critical. In a specific analysis, it is important to see assets, sales and expenses pertaining to a specific object, kind of activity, system or subsystem, and interpret the results accordingly.

[10] http://www.merriam-webster.com/dictionary/asset

available resources (Assets) within a given period [2]. We believe (as a second hypothesis) that this value can also be understood as "ideality", but not with regard to the product but to the entire system during a given period. In this case, assets are the resources that were available to the company and are being consumed during the production; they are essentially similar to $\sum C$ in the (4) ideality formula. This value shows which resources or assets the company used to manufacture all the required product volume (suggesting that Sales ~ $\sum F$, first hypothesis, see above). In [1], we introduced the name of "organization ideality" for that value (Sales/Assets ~ $\sum F/\sum C$). Our further investigations (see below) showed that there can be another, more exact name for this parameter: "process ideality". The term "process" shows that this value pertains to a specific period of time and covers the whole "useful functionality" implemented on these assets/resources.11 Similar to the case of product ideality, we can notice that the increase in organization ideality Iorg also increases the ROA value, in line with our goal of linking together TIPS tools and economic business indicators.

As a result of our rearrangements, the DuPont formula now looks as follows:

$$ROA = (1 - 1/Ip) * Iorg \qquad (6)$$

where Ip is product ideality

and Iorg is organization/process ideality.

To tell between the ROA formulae (1), the DuPont model (2) and the (6) formula, we shall refer to the latter as the TRIZ-DuPont formula and understand it as a transformation of the (2) formula using the TRIZ concept of ideality. This formal transformations provide some insights regarding explaining TRIZ concepts for economists, but it’s only the first step, like “play of words”. In order to prove this connection, we have to show practical usability of TRIZ tools for improvement of economical performance indicators in real TRIZ projects. This is a goal of second part of the article.

3. TRIZ-DuPont model. Case studies from TRIZ practice

To see how these methods work in practice, we selected two well-known cases from TRIZ practice, kindly provided by Simon Litvin, TRIZ Master, currently CEO at Gen-TRIZ.

Case 1. Development of new teeth whitening agents.[12] Background: P&G was about to lose its market for teeth whitening agents because of significant scattering in the efficiency of its products. The product (a compound for domiciliary teeth whitening) was a polymer tray filled with whitening gel. It had to be put on the teeth overnight, for a week. Business challenge: create a product that could become a market leader. We shall not describe the whole decision-taking

[11] In this regard, "organization ideality" and "process ideality" should be understood as synonyms, each of them emphasizing some feature of the same Sales/Assets entity.

[12] Start of quote from S. Litvin's studies

process here and limit ourselves to say that the key contradiction was set forth as follows: "The concentration of peroxide should be high enough for efficient whitening and low enough to ensure gum protection." Then, through applying Function-Oriented Search, the generalized function was as follows: "release of high concentration substances (through thin films)", leadership area: systems for drug delivery into the organism; leadership system: nicotine patches. Eventually, P&G launched the WhiteStrips®, in the U.S. in 2000 and in Canada in 2002. During the first year, the sales came up to $129.6 million and appeared on the top list for non-food goods. The product gained over 45% of whitening products market. WhiteStrips ensured double-digit growth of sales volumes (18%) and net incomes (19%) for the company.[13]

Economically, the outcome of this case may be interpreted as follows, using the TRIZ-DuPont formula. The source product ideality level, Ip, showed that it was not functional enough, this resulting in decreasing sales and ROA in general. Incrementing innovations failed to drastically improve the Ip, especially since each innovation like these requires additional investments that make Assets growth (through amortization of the investments for R&D). The contradiction revealed through analysis showed that the consumer is in need for two key functions; however, each of them was implemented weakly in the products, because a "compromise" should have been kept: "The concentration of peroxide should be high enough for efficient whitening and low enough to ensure gum protection." Let us say (metaphorically and tentatively) that each function was implemented by 45% in order to have the compromise observed, while the percentage required to satisfy the customers was 90% for each one. Accordingly, the overall functionality of the available product was ∑F(old) = 45% + 45% = 90%. Due to the peculiar nature of the TRIZ instrument, the solution allowed to eliminate the contradiction instead of "optimizing", thereby making it possible that both functions be kept with at a top level. The overall functionality of the new product was now much higher (∑F(new) = 90% + 90% = 180%, using the same tentative numbers), which was why the new product dramatically changed its market position - and so did the company in general.

Using this example we can easily generalize the TRIZ logic of solving contradictions as a peculiar and very powerful product development instrument, without anything "mystical" or "esoteric" about that. The contradictions in the implementations of the functions that the consumers need do not allow them to be fully efficient. The compromise logic reunites them, each of them not fully implemented. Meanwhile, the action of "eliminating" the contradiction, unites the top levels of implementing functions within one product, thereby ensuring its competitive advantage. In this regard, we can say that the TRIZ methods are a way to produce BCG Matrix'[14] "Stars" on a regular and systematic basis, with significant perspectives for market and company growth.

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[13] End of quote from S. Litvin's studies

[14] https://en.wikipedia.org/wiki/Growth%E2%80%93share_matrix

Case 2. Paper production process and equipment[15]. "Background: How to decrease capital cost of the paper production process? The current technology contemplates the use of 500 to 1,000 kg of water to make 1 kg of dry paper. Therefore, the capital cost and operating expenses turn out to be quite high. Intermediary problem: How to decrease water consumption in paper production? The solution was developed based on a functional approach. First, the functions of water in the technological process were analyzed (physical binding and moving of the fibers). The key problem revealed consisted in finding ways to ensure "waterless" movement of fibers, while keeping the "water" way of binding them together. As a solution, it was suggested to use steam, which is moist enough to bind fibers together, but the volume of steam required to do so is 500 times less than that of water. Business result: capital cost decreased by 28%. The new process is much more stable and sustainable since there is no more need to recycle water."[16]

This case can illustrate the role of TRIZ tools in improving the second part of the TRIZ-DuPont formula, to-wit, the organization/process ideality, Iorg. Other things (production/sales volume) being equal, the new technical system acting upon a different principle obtained through using the Function Oriented Search (FOS) TRIZ tool can reach the required figures using less resources (Assets 28% lower), therefore significantly increasing Iorg and the overall ROA. In this case, efficiency grows thanks to more advanced production organization and equipment functioning, while the product (paper) stays unchanged; basically, we can believe that product ideality, Ip, does not change, either. This example is also easily generalized for those components of the product portfolio that BCG Matrix calls “Cash Cows”, when the market has stopped to grow and companies/products compete through lowering expenses. TRIZ tools are a way to find the solutions that correspond to the most advanced developments but in other fields, then adapting them for the situation in question.

4. Conclusions and study perspectives

In his early works, G.S.Altshuller spoke of a difference between "engineering" and "inventing" problems. The difference was that the first ones were usually handled by "regular", well-known and generally accepted tools, so the result could also be nothing but regular, market-limited, exactly because it was "the way everyone does". Such solutions are unlikely to bring any result beyond average. In contrast, the second type of problems is solved using "unobvious" inventive ways, bringing forth "powerful" and "original" solutions. This, in its turn, creates a background for getting better results, with economic figures above the market averages. In this study, we transformed the DuPont model into the TRIZ-DuPont one and thereby eliminated the wall between those two types of solutions and tools, showing the unified and objective component of market excellence: through outstanding product and/or process organization ideality. The source economic models were transformed into engineering/economic and then into inventive/economic ones. This approach does in no way pretend to depreciate the TRIZ uniqueness; on the contrary, we believe that it emphasizes it, since we get a chance for unbiased comparison of the results of using various engineering approaches and methods (including such a peculiar one as TRIZ).

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[15] Start of quote from S. Litvin's studies

[16] End of quote from S. Litvin's studies

From the practical point of view, we can say that this inventive/economic logic creates new, proactive opportunities for company portfolio management. The key components of a successful company's project portfolio, “Stars” and “Cash Cows”, are no more expected to "fall down from the sky" or to appear from nowhere. The TRIZ-DuPont model lays a background for systematic generation of projects beating the market, and this background is of scientific nature, using wide range of TRIZ instruments.

This is what we see as perspectives for subsequent research intended to deepen the understanding and the functional nature of the connection between TIPS tools and business results:

A) Detailed development of the BCG Matrix model and other approaches to portfolio management, based on the TRIZ-DuPont model.

B) Analysis of the special features of using TRIZ tools in project management and their ability to affect the economic indicators of the projects.

C) Studying the peculiarities of TRIZ projects, like TRIZ consulting projects, and finding the hard factors of their outstanding economic efficiency.

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THE STUDY OF INNOVATION AND IMPROVEMENTS OF THE GD-K77 RIKEN SINGLE-POINT TYPE GAS DETECTOR BY APPLYING TRIZ

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Abstract

This study focused on Riken GD-K77 attracting Single-Point Type Gas Detector improvements. We want to extend the life period of the detector without lifting the costs of manufacturing the detectors. We used Function Analysis and Cause-Effect Chain Analysis to find out the cause of the detector's failure. We found out that the pump's failure is the main reason of the detector's failure. The aging of the rubber rings is the dominating factor of the pump's failure, and heat and oxygen effect aging a lot. Due to the reason mentioned above, we used Contradiction Matrix and Inventive Principles to design a protection box covers the rubber ring. We will fill in the inert gases or make the space vacuum inside the box to separate heat and oxygen away from the rubber rings. This design may increase the life period of the rubber rings and may thus decrease the chance of the detector's failure.

Keywords: Riken GD-K77, Single-Point Type Gas Detector, Function Analysis, Cause-Effect Chain Analysis, Inventive Principles, Aging of the Rubber Rings

1. Research Background and Motivation

Semiconductor industries play an important role in Taiwan. A variety of toxic gases are used in semiconductor fabrication plants, so that single point gas detectors are significant for safety controls[13,14,16]. Single point gas detectors not only warn the people inside the building but also send the messages including type of gases leaking and the location of the leakage[2,3]. The latter function helps the emergency personnel deal with the accident as quickly as possible. Through quick management of the accident, it would cause less damage[1]. Thus, we want to improve the stability of the detectors.

2. Methods

2.1 Research Conditions

The research is based on the functional analysis and cause-effect chain analysis method of TRIZ theory. There are some conditions we set for the improvements. They are as follow:

(1) The configuration of the single point gas detector will not be changed.

(2) We uses Riken GD-77D single point gas detector as the study object.

2.2 Research Methods

The study spotted harmful or insufficient functions of the single point gas detector that affect its operation with the Function Analysis of TRIZ[4,5,7]. Technical contradictions were used according to the description of problems at each stage to further deduct whether there were contradictions in configuration. After that, corresponding inventive principles were found out and TRIZ solution triggers worked out solutions that solved the problems. At last, an assessment was carried out to check whether the solution could achieve anticipated objectives. We displayed the research processes as figure 1.

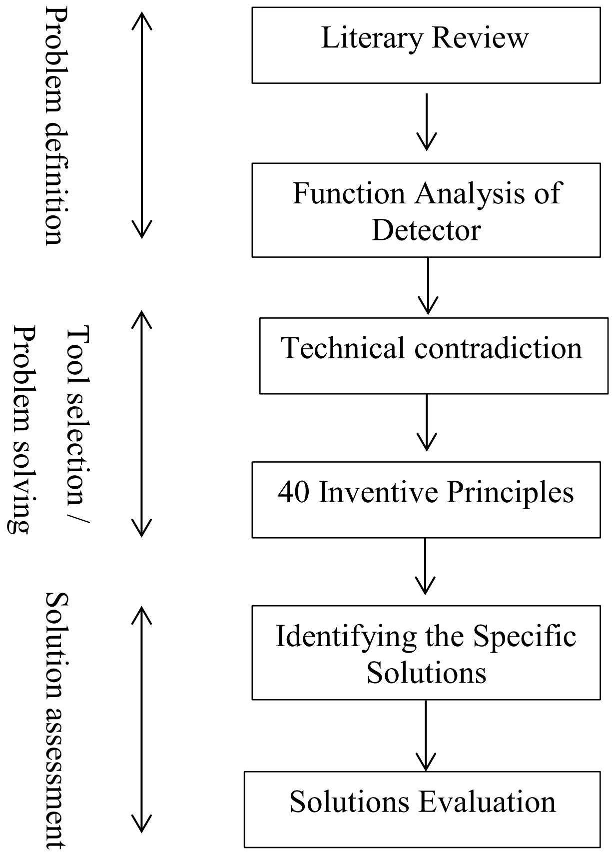

Fig. 1. TRIZ Process Improvement Plans

2.2.1 Use of TRIZ Inventive Principles

This study spotted the problems of Riken GD-K77 gas detectors[14,15], and worked out the solution for the problems by finding out the inventive principles with the contradiction matrix of TRIZ.

2.2.2 Contradiction Matrix

This study aims to explore the operation of Riken GD-K77 single point gas detector with hands-on experience, so the structure of the detector was analyzed. When the contradiction matrix was used, the study followed the following steps:

(1) Describing problems: Describe the problems that occur during the operation of the single point gas detector.

(2) Analyzing problems: Spot good and bad features before finding out the corresponding 39 parameters and locate corresponding inventive principles out of the 40 principles in the contradiction matrix[6,7,8,12].

(3) Working out a solution: Think over how to use the inventive principles located in Step 2 and find out an innovative use to solve the problems[9,10,11].

3. Results and Discussions

3.1 Problem Description

Hands-on experiences revealed that the gas detectors in certain technology companies are often under repair due to the breakdowns caused by fatigue after being used for over 5 years. The repair causes interruption of monitoring, which leads to increasing risks.

3.2 Function Analysis of the Gas Detector

3.2.1 Component Analysis of the Gas Detector

The components of the gas detector include a case, a battery, a mainboard, a pump, et al, super-system 's components are toxic gas, people et al. Gas detectors detect toxic gas by move toxic gas to changie the electrode of the sensor.

Table 1.

Component Analysis of the Gas Detector

<table>
<tr><th>Engineering System</th><th>System Components</th><th>Super system Components</th></tr>
<tr><td>Riken GD-K77 single point gas detector</td><td rowspan="3">Case
Battery
Mainboard
Sensor
Electrolyte
Pump
flow regulator
flowmeter
gas inlet</td><td rowspan="3">Toxic gas(Target)
People
Buzzer
Power</td></tr>
<tr><td>Main Function</td></tr>
<tr><td>Move toxic gas
(Main benefit : Avoid people contact gas)</td></tr>
</table>

3.2.2 Interaction Analysis of the Gas Detector

The analysis aims to identify the components of the system and super- system, getting to know whether the components are interconnected. Interaction Matrix of the single point gas detector is showed in table 2.

Table 2.

Interaction Matrix of Gas Detector

	1	2	3	4	5	6	7	8	9	10	11	12	13
1.Gas	x	-	-	-	-	+	+	-	-	+	-	-	+
2.Case	-	x	+	+	+	+	+	+	+	+	-	-	-
3.Battery	-	+	x	-	+	-	-	-	-	-	-	-	-
4.Mainboard	-	+	-	x	+	-	-	-	-	-	+	+	-
5.Sensor	-	+	+	+	x	+	-	-	-	-	-	-	-
6.Electrolyte	+	+	-	-	-	x	-	-	-	-	-	-	-
7.Pump	+	+	-	-	-	-	x	-	+	-	-	+	-
8. flow meter	-	+	-	-	-	-	-	x	+	-	-	-	-
9.Flow regulator	-	+	-	-	-	-	+	+	x	-	-	-	-
10.gas inlet	+	+	-	-	-	-	-	-	-	x	-	-	-
11.buzzer	-	-	-	+	-	-	-	-	-	-	x	-	-
12.power supply	-	-	-	+	-	-	+	-	-	-	-	x	-
13.People	+	-	-	-	-	-	-	-	-	-	-	-	x

3.2.3 Function Models of the Gas Detector's System

Function Model Analysis was carried out based on the interactive relations among the components of the system and super-system. It revealed the operation of the system, the changes occurred when parts were combined or separated and what kind of function among components interactive functions performed with. Function Models of the Detector's System were show in table 3 and figure 2.

The case contains batteries, and their interactive effect provides the power for the mainboard and the pump. The pump move toxic gases. The flow regulator adjusts the needed gas. The flowmeter tells how much the gas is. The gas inlet accommodates the toxic gas and moves the gas to the electrolyte. The mainboard transmits the data to onsite personnel judge to help it decide whether an evacuation is needed .

Table 3

Function Models of the Gas Detector's System

Function	Rank	Performance level
gas		
Hurt people	Additional	Harmful
Change polarity of Electrolyte	Additional	Normal
Case		
Hold Battery	Auxiliary	Normal
Hold Mainboard	Auxiliary	Normal
Hold Sensor	Auxiliary	Normal
Hold Electrolyte	Auxiliary	Normal
Hold Pump	Auxiliary	Normal
Hold Flow regulator	Auxiliary	Normal
Hold flow meter	Auxiliary	Normal
Hold gas inlet	Auxiliary	Normal
Battery		
Powers sensor	Auxiliary	Normal
Mainboard		
Powers buzzer	Additional	Normal
Sensor		
Informs mainboard	Auxiliary	Normal

Function	Rank	Performance level
Pump		
Move gas	Basic	Insufficient
Flow regulator		
Control pump	Auxiliary	Normal
Flow meter		
Monitor Flow regulator	Auxiliary	Normal
Gas inlet		
Hold gas	Basic	Normal
Power supply		
Poweres mainboard	Additional	Normal
Poweres Pump	Additional	Normal
Electrolyte		
Informs sensor	Auxiliary	Normal

Rank: Basic – object ; Auxiliary - between system components ; Attached - between system components and Supersystem

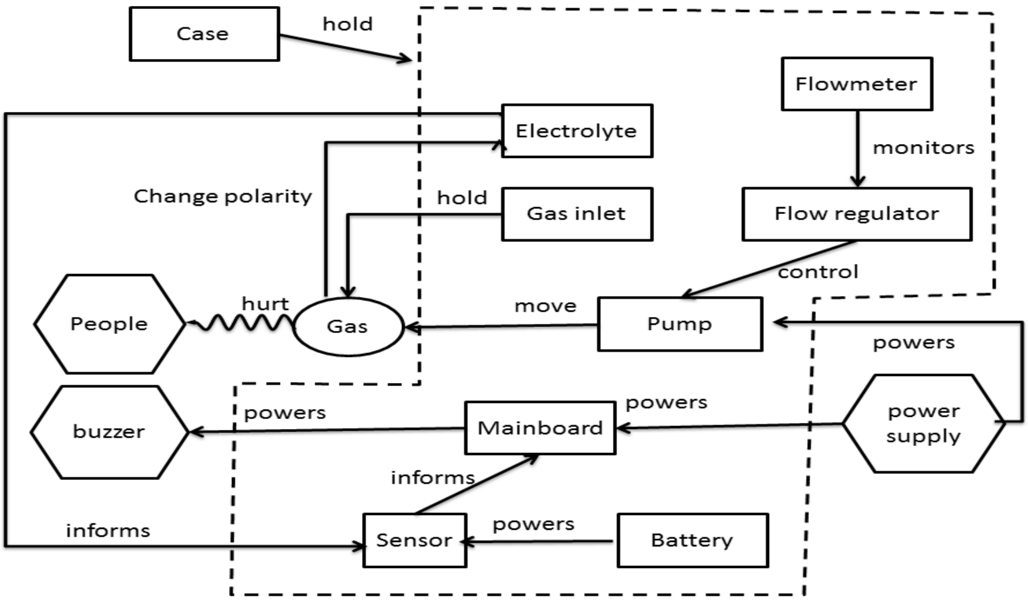

Fig 2. Function Models of the Gas Detector's System

3.2.4 Disadvantages of the Gas Detector's Functions

It was found that the toxic gas in the atmosphere will not be detected if the pump did not have enough power to move toxic gas from one side to the other. The analysis of the pump was carried out with Function Analysis.

Table 3

Disadvantage of the Gas Detector's Functions

No.	Disadvantage of the Functions
1	pump have not enough power to move toxic gas

3.3 Function Analysis of the Pump in the Detector

Detection of the toxic gas will be interrupted when the detector fails. We now know that if the pump did not have enough power to move toxic gas from one side to the other. Function analysis was carried out for spotting the problem more precisely.

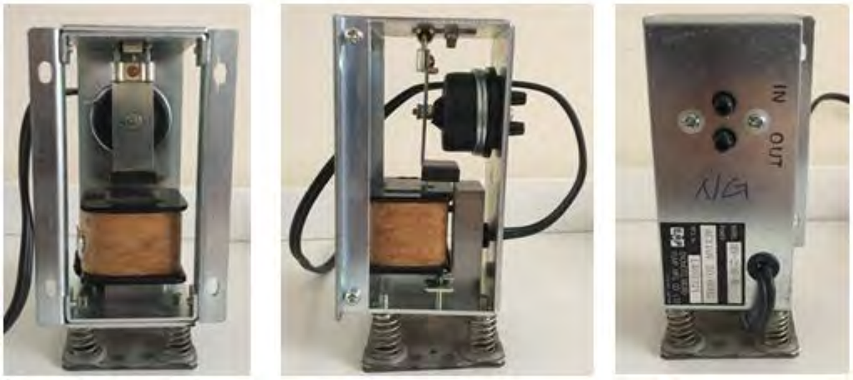

Fig. 3. Components of the of the Pump in the Detector

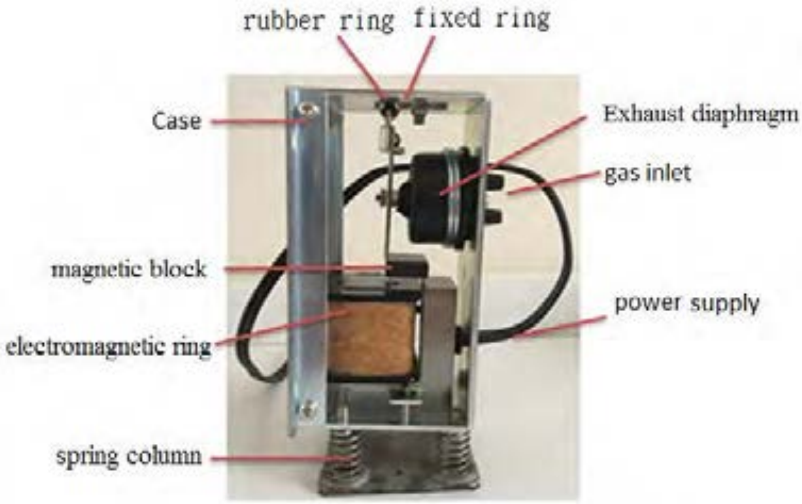

Fig. 4 Components name of the of the Pump in the Detector

3.3.1 Component Analysis of the Pump in the Detector

A main function of the pump is to move toxic gases, which avoids the contact between personnel and the gas. The components of the pump include an electromagnetic ring, flow regulator, magnetic block, exhaust diaphragm, pump casing, spring column, fixed reticle, and rubber, as well as power in the peripheral part. The main function of the pump is to move toxic gases, so the object that the pump moves is toxic gases.

Table 5

Component Model of the Pump in the Detector

Engineering System	**System Components**	**(Associated)Supersystem Components**
Pump in the Detector	Electromagnetic ring Flow regulator Magnetic block Exhaust diaphragm Pump casing Spring column Fixed ring Rubber ring	Toxic gas(Target) Power supply
Main Function		
Detect toxic gas (Main benefit: Detection gas)		

3.3.2 Interaction Analysis of the Pump in the Detector

To identify the components are in contact with each other or not, the following table showed the available interaction analysis.

Table 6

Interaction Analysis of the Pump in the Detector

	1	2	3	4	5	6	7	8	9	10
1.Toxic gas	X	-	-	-	-	+	-	-	-	-
2.power supply	-	X	+	+	+	-	-	-	-	-
3.Electromagnetic ring	-	+	X	-	+	-	-	-	-	-
4.flow regulator	-	+	-	X	-	-	-	-	-	-
5.Magnetic block	-	-	+	-	X	+	-	-	-	-
6.Exhaust diaphragm	+	-	-	-	+	X	-	-	-	+
7.Pump casing	-	-	-	-	-	-	X	+	+	-
8.Spring column	-	-	-	-	-	-	+	X	-	-
9.Fixed ring	-	-	-	-	-	-	+	-	X	+
10.Rubber ring	-	-	-	-	-	+	-	-	+	X

3.3.3 Function Model Analysis of the Pump in the Detector

This section analyzed the pump of a single point gas detector. It helps readers get to know the detector's structure, its' peripheral parts and its' operation. Table 7 showed that the main function of the Riken single point gas detector is to move toxic gases.

Table 7

Function Model Analysis of the Pump in the Detector

Function	Rank	Performance level
Spring column		
Support the pump casing Dampen the pump casing	Auxiliary Auxiliary	Normal Normal
Pump casing		
Holds Fixes ring	Auxiliary	Normal
Fixed ring		
Holds Rubber ring	Auxiliary	Normal
Rubber ring		
Move Magnetic block	Auxiliary	Insufficient
Magnetic block		
Move Exhaust diaphragm Move Electromagnetic ring Attrit Electromagnetic ring	Auxiliary Auxiliary Auxiliary	Insufficient Normal Harmful
Exhaust diaphragm		
Move Toxic Gas	Basic	Insufficient
Flow regulator		
Control Power supply	Additional	Normal
Power supply		
Provide electricity to Electromagnetic ring	Additional	Normal

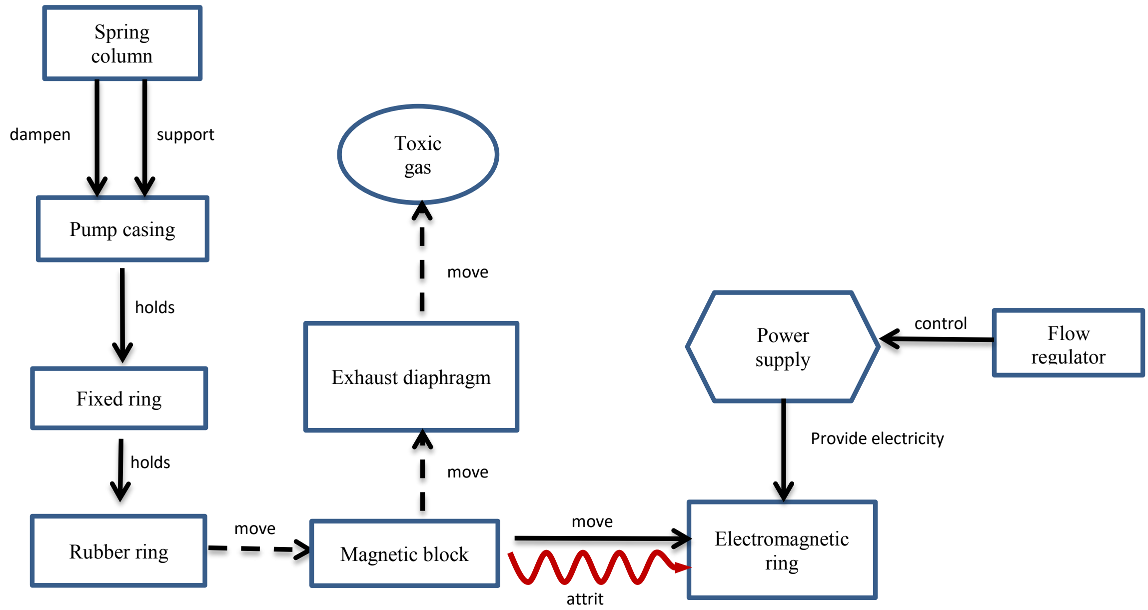

Fig. 5 Function Model of the Pump in the Detector

3.3.4 Disadvantages of the Pump in the Detector

The analysis of the pump showed that an exhaust diaphragm will not move the toxic gas to the expected point. If the magnetic block does not move the exhaust diaphragm to the expected point, it will attrit the electromagnetic ring. The cause-and-effect relationship will be analyzed later.

Table 8

Disadvantages of the Pump in the Detector

No.	Disadvantages of the Functions
1	The exhaust diaphragm moves the toxic gas to the expected point insufficient.
2	The magnetic block moves the exhaust diaphragm to the expected point insufficient.
3	The rubber ring moves the magnetic block to the expected point insufficient.
4	The magnet block attrit the electromagnetic ring

3.3.5 Cause-Effect Chains Analysis of the Detector's Pump

The Cause-Effect Chains Analysis inside a pump revealed that the stress caused by the heat sink in the electromagnetic ring will increase the level of aging of the rubber. The contact between oxygen and ozone of rubber materials will also increase the level of aging. Aging leads to the failure of the magnetic block, which causes the pump to lose its function of moving the gas.

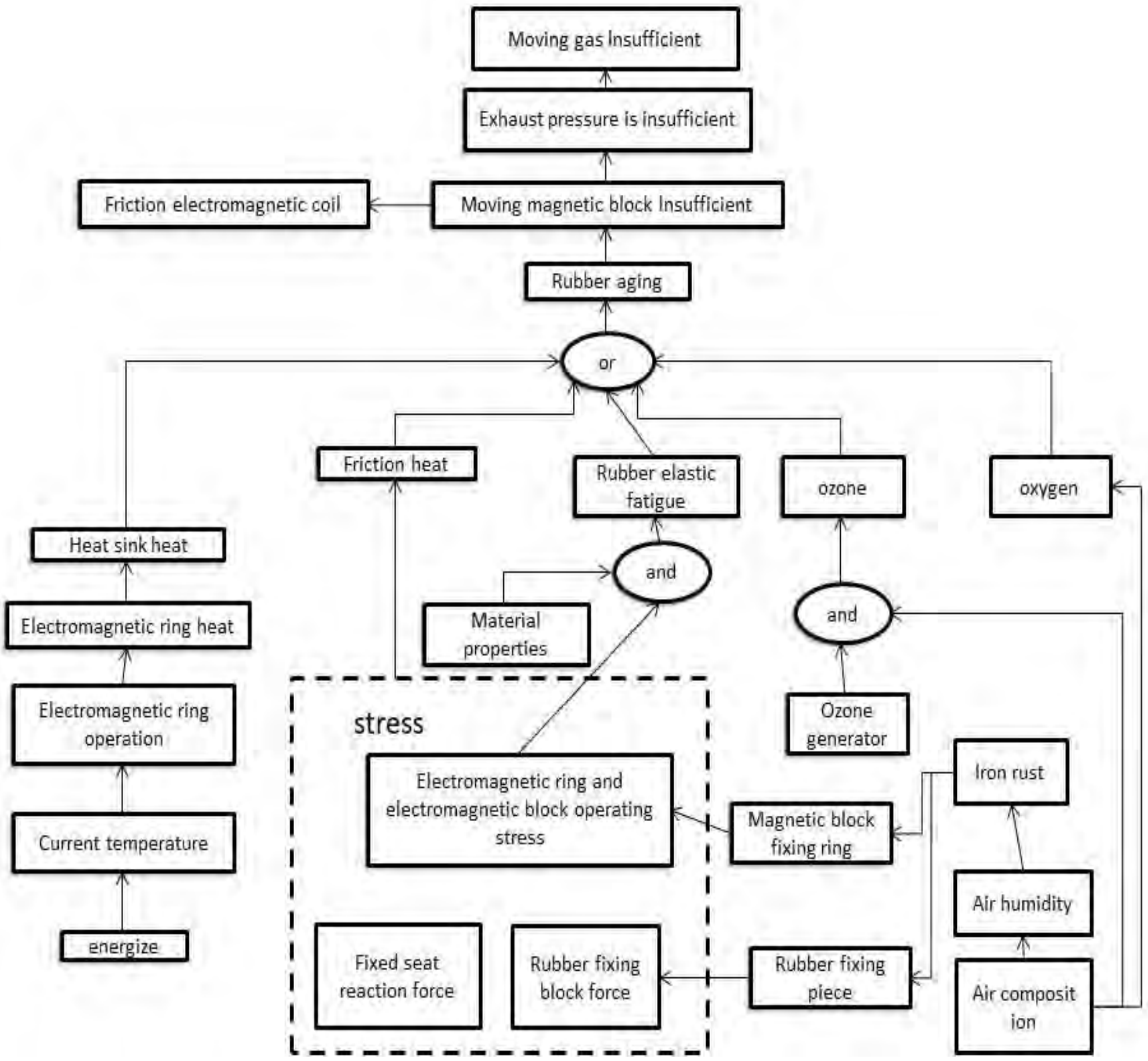

Fig. 6 Cause-Effect Chains Analysis of the Detector's Pump

3.4 Creative Design with TRIZ Contradiction Matrix and Inventive Principles

3.4.1 Improvement of Rubber Used in the Pump

(1) The situation: We want to use rubber material to reduce noise and vibration.

(2) Contradictory point:

IF the ring material of exhaust diaphragm used rubber material,

THEN it can reduce the noise and vibration of the pump, BUT rubber material ages easily. When the ring ages , it will cause the interruption of gas detection.

(3) Engineering parameter and Inventive Principle: The researcher hoped to use the rubber materials to decrease noise and vibration when the magnetic block is working, corresponding to the engineering parameter "31 Inherent damaging effect". On the other hand, we hoped that rubbers will not be easily worn so that frequent repair is unnecessary, corresponding to the engineering parameter "27 Reliability". The inventive principle obtained by the contradiction matrix was improving rubber materials.

Table 9

Contradiction Matrix of the Rubber Material Used in the Pump

Worsening Parameters / Improving Parameters	27 Reliability
31 Inherent damaging effect	24 2 40 39

Corresponding to the contradictory matrix of the invention of the principle of 24, 2, 40 and 39, rubber materials can be modified as the direction of the proposed design, the proposed way to the feasibility and ideal.

(4) Inventive Design: The inventive principles of "39 Inert Environment" and "40 Compound Materials" were adopted in order to improve the pump. The process of considering the design was shown as follows:

(i)"39 Inert Environment": Design a protection box covers the rubber ring, filling the place in which rubber is placed with inert gases or make the space vacuum inside the box. The inert gases isolates the air from the rubber, which will avoid rubber ageing because of air contact.

(ii)"40 Compound Materials": Replacing rubber with heat-resistant and anticorrosive materials.

3.4.2 Heat Transmission from the Electromagnetic Ring to Rubber Ring

(1) The situation: we hope to use the electromagnetic ring to produce cathode. Cathode will make the magnetic block to move the membrane and the toxic gas will thus be moved.

(2) Contradictory point:

IF electromagnetic ring was used to produce cathode,

THEN it can make the magnetic block to move the membrane and the toxic gas will thus be moved,

BUT it will produce heat, which will decrease the quality of the rubber ring.

When the ring ages, it will cause interruption of gas detection.

(3) Engineering parameter and Inventive Principle: If the magnetic ring is used to produce cathode to move the toxic gas, the magnetic ring will produce heat. Heat will cause aging of the rubber.

The researcher hoped to use the electromagnetic ring to produce magnetic forces that move the diaphragm, corresponding to the engineering parameter "19 Forces needed for the movement of objects". He did not want to see the heat coming out, corresponding to the engineering parameter "17 Temperature".

(4) Inventive Design: The inventive principles of "3 Local Quality" are adopted in order to improve the pump. The process of thinking were as follows:

"3 Local Quality" The space in the pump was filled with air. Heat will transmit to rubber ring through air. We don't want the heat to reach the pump so we may make places around the rubber ring covered by a case. Then, put inert gases in the case to isolates the air from the rubber. It will avoid the aging of the rubber ring.

Tab. 10 Contradiction Matrix of the Electromagnetic Ring

Worsening Parameters / Improving Parameters	27 Temperature
19 Forces needed for the movement of objects	19,24,3,14

4. Conclusions and future improvements

The study showed how to innovate the single point gas detector with TRIZ. If we design a protection box covers the rubber ring. We will fill in the inert gases or make the space vacuum inside the box to separate heat and oxygen away from the rubber rings. Our future research will focus on how to manufacture the device we came up.

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TRIZ AND SCIENTIFIC METHOD OF COGNITION: COORDINATION OF APPROACHES

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Abstract

TRIZ algorithms are based on paradoxical logic, which differs from traditional logic of engineering problem solving. It is possible to increase effectiveness of TRIZ if we combine it with the scientific method of cognition.

The report shows that an effective problem solving algorithm should be based not only on TRIZ approaches, but also on methods of obtaining new knowledge. By the scientific method, new knowledge can be obtained by observation of a phenomenon, analysis of observation results, suggesting hypotheses and testing them. A solving of any inventive problem means obtainment of new knowledge: how to fix a disadvantage, how to improve a machine or equipment.

The algorithm of improving problem situations (AIPS) developed by the author includes the scientific method of cognition. By this algorithm, it is necessary to collect information about machine structure and operating (observation stage), then to analyze obtained information for revealing the problem core: a conflict and its causes. The most important stage is hypotheses suggesting. It is necessary to propose different ways of conflict eliminating. The testing stage is the stage of solving the technical problems, which are formulated based on hypotheses.

1. Use of scientific method in inventive problem solving

The difficulties of mastering TRIZ-based approach are largely hidden in the fact that it is based on paradoxical logic, which is different from the traditional logic of solving problems, applied by scientists, specialists and engineers of the companies. TRIZ algorithms and the very approaches to solving problems don't fully match the method of scientific cognition [1].

In our opinion, the process of inventive problem solving will largely benefit, if it is based not only on TRIZ principles, but also on scientific method for obtainment of scientific knowledge. Solving an inventive problem means obtainment of new knowledge about correcting something in a problem machine, equipment or their environment, about eliminating a problem, which worries us.

The process for obtaining new knowledge includes the following steps:

1. Monitoring the object of research
2. Analyzing the results of monitoring
3. Setting forth hypotheses
4. Creating conditions for checking the hypotheses
5. Checking hypotheses and formulation of new knowledge.

The first two items are analytical part of the process, while three last ones constitute its synthetic part.

It is rather convenient to use the actions, which are analogous to the process of obtaining scientific knowledge, in solving inventive problems (Fig.1). The following sequence manifests itself here.

First we monitor some phenomenon, for example, the functioning of a problem technical device, gather data on its structure and functioning as well as on the problem associated with this phenomenon. After that the analysis proper is conducted, we try to find out the essence of the problem – in what place, under what conditions and due to what reasons the conflicting interaction took place. The next step is setting forth hypotheses concerning the methods for elimination of the conflict existing within the system. Further on, we need to organize the check of hypotheses, which were set forth, but prior to that we shall have to think about how to do it in this particular situation.

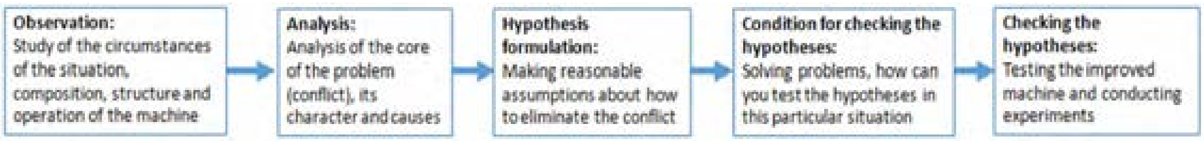

Fig. 1. Solving an inventive problem as obtainment of scientific knowledge

If we look at the evolution of TRIZ, we can see that this evolution is in keeping with the above-quoted scheme. TRIZ methodologies at early stages of their evolution were concentrated at solving the problems, which emerged from some problem situation. It was supposed a priori that the solver knows, which result he had to obtain, however, it wasn't clear how to obtain this result. If it was clear what result should be obtained and how it could be done, no problem existed at all. However, practice has shown that detached problems are rarely encountered in practical consulting, most often at the input we have a complicated problem station, in which the problems to solve have not yet been singled out.

Analytical tools start to be actively used nowadays in addition to solving methodologies and tools. Application of function and flow models, models of the processes, different models of a useful system and cause/effect analysis have become ordinary for studying a problem situation. Such a broadening of TRIZ competence can be only welcomed, since it offers an opportunity to enhance the quality of obtained ideas (Fig.2).

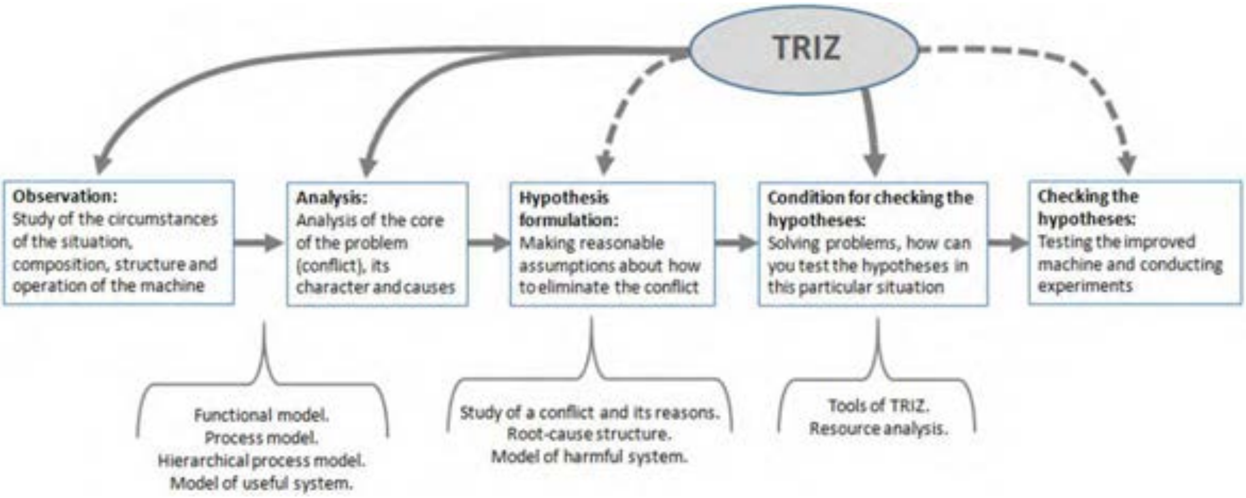

Fig. 2. TRIZ and steps of scientific method

At the same time insufficient attention is given in TRIZ to stages of setting forth the hypotheses and checking them. And this is regrettable: following the logic of scientific method, which was optimized during the centuries and proved its effectiveness, could significantly assist the solving of problems. When a problem is solved, the information is gathered fairly quickly and it is difficult to generalize it: the solving process can come to a dead end. The hypothesis, describing a possible way of solving a problem, can function as an intermediary link here. Formulating a hypothesis, we create a supposition about the method for attaining the set goal and delineate the possible way of solving a problem.

The working hypothesis is based on understanding and explaining the reasons of the conflict. It describes the transformations of the problem situation and of the machine, which are necessary for elimination of the conflict and points out, what conditions should be created in a certain zone of the machine in order to eliminate the conflict.

It is necessary to verify the advanced hypothesis: to introduce changes into a problem device and to perform testing experiments. If it is complicated and expensive, the test is carried out on models – object models, mathematical, computer and other models. However, it is by far not always understandable, how to provide for conditions described in the hypothesis. In this case an inventive problem emerges. It is necessary to solve this problem and to answer the question: how is it possible to transform the device, in order to create conditions described in the hypothesis? Serious contradictions may occur at this stage, which should be resolved using the tools of classic TRIZ.

2. Function and structure of AIPS-2015 algorithm

Based on the above-quoted approach we developed an algorithm for correcting problem situations AIPSH-2015, which organizes basic TRIZ tools into a single unit, the aim of which is solving inventive problems and correcting problem situations. This algorithm is a logical continuation of TRIZ-based algorithms developed by G. S. Altshuller. analytical and solving tools, applied in TRIZ are extensively used in it. An important role in this algorithm is played by key provisions of the general theory of strong thinking (OTSM) developed by N. N. Khomenko. Besides, in creating the algorithm we tried to make the best of our long-term experience of problem-solving, acquired at different companies, first of all at SAMSUNG and POSCO (Korea).

The work with an algorithm starts with the description of a source *problem situation*. Our goal is to improve a certain problem situation, i.e., to obtain an *improved situation*, in which the non-desirable effect is eliminated. Algorithm presupposes the work on the situation in three stages (Fig. 3).

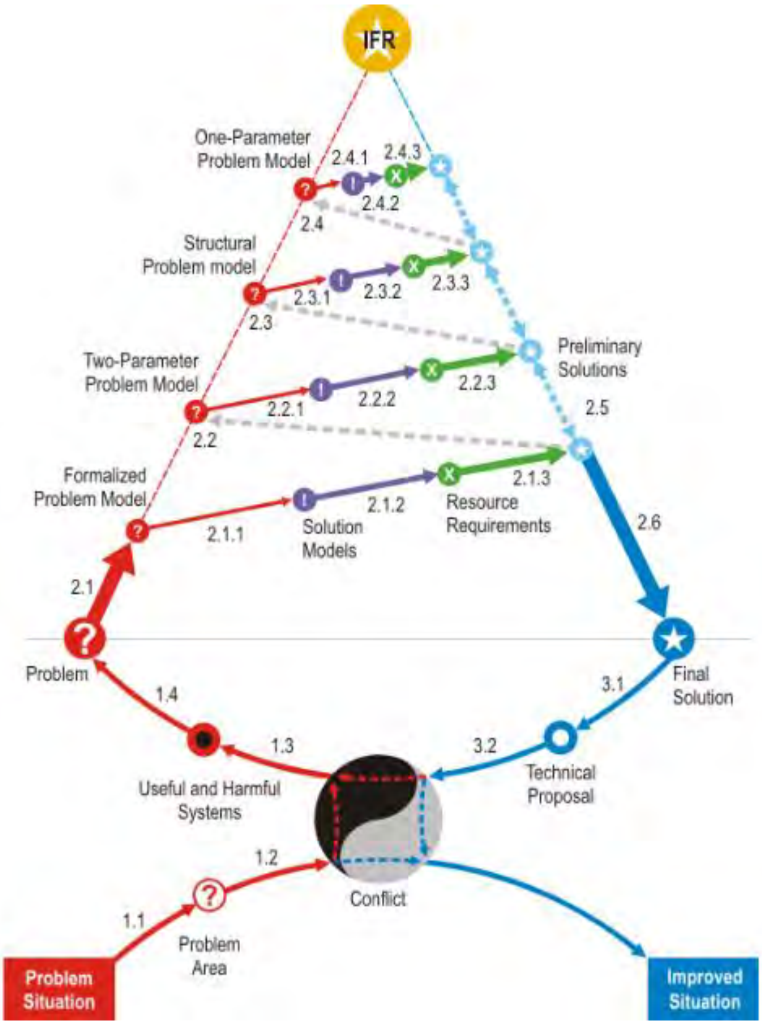

Fig. 3. Scheme of a problem situation improvement

First comes the **analytical stage** – we analyze the situation, try to understand why the undesirable effect is encountered and under what conditions it would not occur. The analysis starts with specifying the problem situation and detaching the undesirable effect. After that follows the transition to the level of engineering device, the machine, the functioning of which is related to problem situation. This part of work is directed at narrowing the field of search and singling out the conflicting interaction of system components. Further on, it is necessary to find out, what reasons cause the conflict and to put forward working hypotheses concerning the methods for elimination of these reasons. The final action of the analytical stage is the formulation of problems.

Thus, the problem situation consists in the fact that in obtainment of a useful product we also get some negative phenomena — *undesirable effects.* Sometimes, there are many undesirable effects in a situation, they can be in a complicated interrelation. Each undesirable effect should be analyzed separately, however, one should start with such an effect, which requires elimination first of all.

ЧIn order to pass over from the problem situation to the formulation of the problem, it is necessary to do a lot of analytical work: to understand, what led to the occurrence of the undesirable effect and what parts of the useful system require correction, to put forward suppositions (hypotheses), under which conditions the undesirable effect will be eliminated. And at the same time the answer to the question of how these corrections will be effected, will be the solution of the problem (Fig.4).

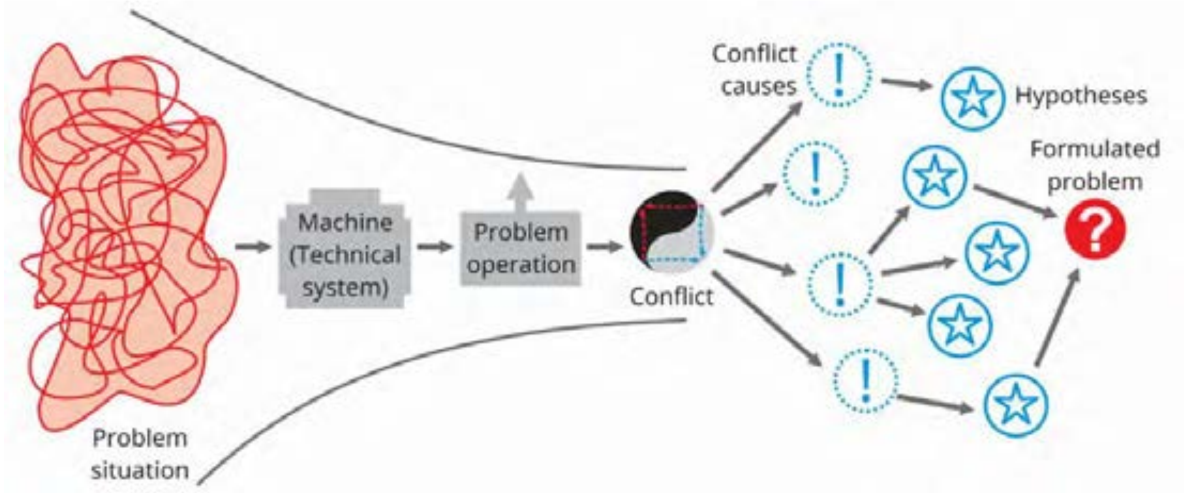

Fig. 4. Scheme of the analysis of a problem situation

Analytical part of the work with a problem situation is performed in four steps.

3.1 Specification of the problem situation

At first it is necessary to understand the circumstances, under which the problem situation occurred, to understand the essence of the undesirable effect, with the production of what useful product the problem situation is associated and what principle is used in obtainment of the useful product.

3.2. Identification of problem operation

At the second step we have to pass over from the description of the problem situation to understanding of where the source of the problem lies.

At first, it is necessary to understand, the functioning of which machine, which equipment is associated with the occurrence of undesirable effect, which particular harmful product appears as a result of its functioning. Further on, we find all necessary information about the machine: its composition and structure, how it works and in what environment it functions. Then we analyze the technological process, performed by this machine, in greater detail.

After that it is necessary to find out, what step of technological process is characterized by generation of that harmful product, with which starts a chain of negative events, leading to undesirable effect. It would enable to identify the problem zone of the machine, the place, where the conflict is generated.

The actions to be taken at this stage are *research and analysis.* The most convenient way of generalizing the information about the machine is to construct models of it. Modeling will allow to identify the most important things, and to present the knowledge of the machine in a concentrated form.

The result of performing this step: the problem operation is indicated, which most probably yields a harmful product, the structure of the system, performing this operation, is identified and relevant features of machine functioning are studied.

3.3 Studying the conflict

The conflict is the imperfection of the machine, harmful interaction of its components, which leads to emergence of a harmful product of the problem operation. In order to identify the conflict, it is necessary to specify, what components of the machine take part in the production of a harmful product, when the conflict emerges, what in particular takes place and where.

At this step it is necessary to take a strategic decision – whether it is necessary to eliminate this conflict at all. For this purpose, it is necessary to find if this undesirable effect is significant enough for spending time, effort and money on elimination of the conflict, or this undesirable effect could be neglected in this case. It means that in this part of the algorithm there is a "bifurcation point": the fork, in which we have to select one of two directions.

If the decision is taken to eliminate the conflict, it should be studied in greater detail. It is necessary to understand the reasons of the conflict, its nature and to trace the entire chain of events, which lead to a negative phenomenon.

In identifying the origins of the conflict our line of reasoning will be as follows.

If a conflict emerges in some place of the machine, it means that "useful" and "harmful" systems act here simultaneously, due to what a harmful product is produced. The useful system has already been analyzed, now it is necessary to identify the components of a harmful system and to understand the mechanism of interaction between the two systems. In addition, it is necessary to study the entire chain of events, which led to the generation of the conflict and to understand the conditions under which it emerges.

The result of performing this step is exact indication of conflicting components and the time of the conflict, list of the most significant reasons of the conflict.

3.4. Putting forth hypotheses concerning the elimination of the conflict and formulation of problems.

Finally, it is necessary to select the directions for elimination of the conflict.

To achieve this, it is necessary to set forth the hypotheses – suppositions concerning conditions under which the conflict will be eliminated. It could be eliminations of the reasons of the conflict, neutralization of its consequences, changing the modes of operation of the given device, change of environment, etc.

At large, the hypothesis is *the description of desired result at the level of the situation,* indication of what particular conditions we should obtain in the problem zone of the machine in order to eliminate the conflict. Here is an example of a working hypothesis: in order to prolong the service life of the micro-chip, it is necessary to reduce its temperature. Based on hypotheses, problems intended for solving are formulated, implying the technologies of "Typical solution" and "Contradiction".

The analysis of the problem situation is a step-by-step motion into the depth, from the known to the unknown. From the understanding of the situation on the whole to technological details, from studying the principles of machine functioning to identifying of conflicting components. It is necessary to find a problem place and to understand, what sort of a conflict between system components exists there. The conflict is the core of our problem, it is the main negative event generating a problem situation.

Having identified a conflict situation, we simplify the problem, i.e., we find one of the unknown values of a complicated equation. Identification of the conflict is an important part of the work, however, it is only one half of the work. We understood the essence of the problem, and then it is necessary to analyze the deep reasons of the conflict and to understand, what potentiality we basically have in terms of eliminating this conflict. The field of search is dramatically broadened: we look for the events, which lead to the generation of the conflict proper and try to take all significant reasons of it into account. It could be either one reason or several reasons. However, having concentrated our efforts on the search for these reasons, we try to review all reasons of this disadvantage at once and we analyze them one after another, which is much simpler. Particularly the set of reasons will enable us to set forth the working hypotheses for elimination of the conflict, while the entire remaining information, received at the first stage will give an opportunity to find the conditions for verification of these hypotheses, i.e., formulate particular problems.

At the second stage we solve the problem, i.e., we find how to create the conditions under which the undesirable effect will not appear. Based on the conditions of the problem, it is possible to create a model of it, to transform it into a model of a solution, to select required resources and to find the idea of a solution. The solving stage of the algorithm is characterized by the following peculiarity: the tools applied constitute one system, which enhances the efficiency of applying them.

Here we act in the following way:

- We formulate the result, which it is required to obtain and find, what hinders the obtainment of this result.
- We find the basic idea, we find the basic idea for obtainment of the required result and define what action should be done for this purpose.
- We select the resources, which we need for the implementation of this idea and the use of this idea for the improvement of a particular machine.
- We find these resources and convert this idea into an actual solution.

It is necessary to repeat this sequence of actions ("what is required – how to obtain – what to use for obtainment – the variant of the solution") several times, every time elaborating the idea of what we need and what hinder sour obtainment of it. Fundamentally, at the second stage we have to specify the method for attainment of the set goal and find the means for implementing this method. In this case it is necessary to reach the mutual harmony of method and means for solving the problem, which requires several iterations of solving the problem.

Fig. 4.1. Solving stage of AIPS-2015

The line of reasoning used in solving an inventive problem is based on the scheme, described by the "Hill" model (Fig.5). The peculiarity of the approach consists in the fact that not the situation itself is transformed, but its model, and then the return to the level of an actual situation takes place and the solution of the problem is worded. The problem, which relates to certain actual objects, is transformed by the conscience into its abstract model. There is an idea at the abstract level: what change is required for the set goal and only then this idea is embodied in an actual object [4].

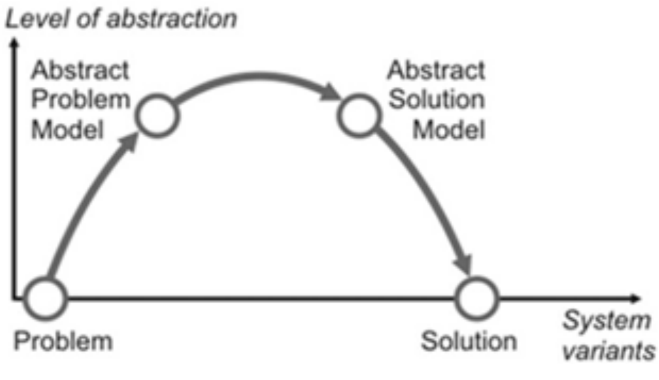

Fig. 5. "Hill" scheme of problem solving.

Three transitions are shown in the scheme:

- From conditions of the problem to the abstract model of the problem;
- From the abstract model of the problem to abstract model of solution;
- From the abstract model of solution to a particular solution.

Special models are used for transition to the abstract level, while well-proven TRIZ tools have been elaborated for the transition from the abstract model of the problem to the abstract solution.

The most complicated solution is the third one. After transforming the model of the problem we obtain a model of solution, which offers a certain fundamental transformation of the system. Further on, it is required to convert this model into an actual solution. For this purpose, it is necessary to find the resource and to incorporate it into the problem system. It is necessary to be able to apply the abstract idea of solution to particular circumstances: to understand, what should be changed in the technical device, what resources could be used for that purpose. Special attention in algorithm AIPS-2015 is given to work with resources: compiling a list of requirements and finding a new resource.

Sometimes it is possible to find at once from the model of solution, what resource we need and to formulate the solution of the problem. However, it happens often that it is by far not obvious and the required resource should be found. It means that the final goal of working with resources consists in finding such a system, in which the disadvantages are eliminated, which are present in the source system.

Example. Work on creating a compact printer using the "Hill" model.

Problem. *What is the way to reduce the size of a jet printer? The width of this device is dictated by the standard size of the paper sheet A4 and the opportunity to print on such sheets should be retained.*

MModel of the problem. *Let us imagine in the generalized form the interaction of the printing head and a sheet of paper. The head performs shuttling motion along the straight line across the sheet and prints the picture. The model of the problem is a section of the straight line. What is the method for making it compact?*

Models of solving. *With the source printer the pathway of a printing head is straight. Here it is possible to ask a question – what is the way of making a section of a direct line compact? How to put a piece of wire into the picket? Coil it into a ring… or cut it into pieces, if the integrity of the wire is of no importance. Transition from the problem to its solution is shown in Figure 6.*

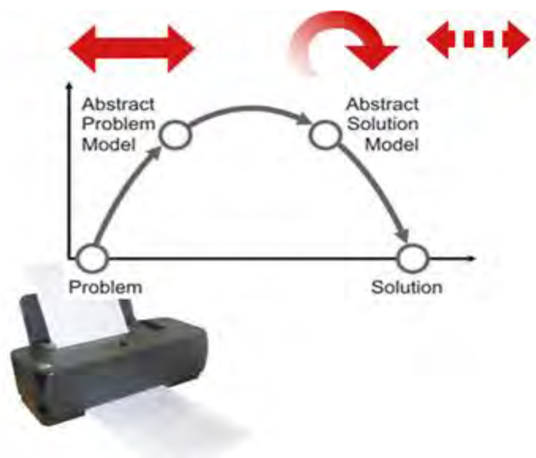

Fig. 6. Obtainment of the model of a solution for a compact printer.

Solution 1. *Embody the printer in the form of a ring, through which a piece of paper rolled into a tube is stretched. Such a "Circular Printer" was proposed by the Korean designer Songyon Lie (Fig. 7).*

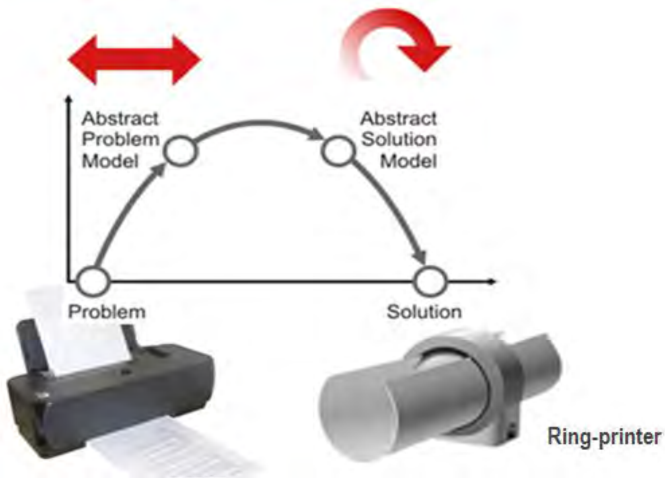

Fig. 7. Obtainment of the idea of a Circular printer.

Solution 2. *To retain only the basic part of the printer – its printing head with control elements. Such a printer, for example, Zuta Pocket Printer, could move along the sheet of paper, one line after another, printing the letters (Fig.8).*

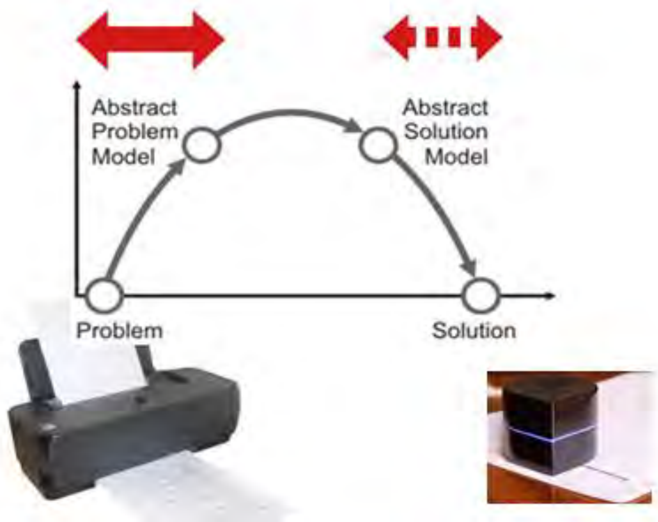

Fig. 8. The idea of a printer as a printing head.

And finally, **at the third stage** it is necessary to analyze the situation one again – to understand, if our hypothesis was right and if it became possible to get rid of the disadvantage. It is necessary to experimentally prove the proposed solution. To elaborate the details of its engineering embodiment and to check, if the problem situation is corrected by the proposed solution. The experiments could be organized both for checking the fundamental workability of the new variant of the machine, and for the elaboration of its parameters and modes of operation. It offers an opportunity to elaborate the design, to perform engineering calculations and to manufacture the required equipment. Thus, the fundamental idea of a solution is transformed into an actual machine.

4. Software product Solving Mill

Algorithm AIPS-2015 was tested several times in solving inventive problems for the company POSCO and was thoroughly optimized. Software product Solving Mill was developed based on it.

The main idea of the Solving Mill is return to origins of "Inventing Machine", that first version, with which this project started. Then there was a wish to create a kind of a software interlocutor, a sort of a "guide" who leads the solver through the problem-solving process and explains what should be done at a certain stage and what result should be obtained.

The idea of a software helper, competent and logical interlocutor, who guides the problem-solving along the efficient algorithm, asks proper questions and reminds what should be done and what attending information should be applied – has great potentiality. The goal of the Solving Mill project is to propose a computer program, which is directly intended for solving an inventive problem from the description of the problem situation to obtainment and valuation of the idea of solution. In many respects it was a success, the software product was successfully tested at POSCO and other companies, in the universities and demonstrated good results.

Fig.9. Solving Mill

The main solving tool of Solving Mill is a template, a kind of a map of solutions, which is filled in by the user. Formulation of contradictions and other models of problems is carried out using mini-algorithms and tools developed in attending disciplines.

It is presupposed that a thorough analysis of the problem situation is carried out, implying the creation of cause/effect interactions and employment of the most efficient tools for solving problems as well as strengthening of obtained solutions using the lines of evolution.

Conclusions

1. Feasibility of coordination of TRIZ methodologies with the scientific methods for obtainment of new knowledge is shown.

2. Setting forth hypotheses for elimination of the conflict plays an important role in inventive problem solving.

3. Algorithm AIPS-2015 and the software product Solving Mill show high efficiency in solving inventive problems.

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TRIZ FOR NEW PRODUCTS: SOLVING "NEVER SOLVABLE" PROBLEMS

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Abstract

SMP Inc. is a leading independent manufacturer and distributor of automotive spare parts. One of the major product categories is Ignition Coils. Decision to manufacture versus resale product is made based on the vehicle in operation number as well as the original part failure on the market resulting in potential sales volume. Main market drivers are product quality and output parameter's characteristics and item price.

One of the important characteristic is Fit and Function, what is very easy to check by Customer by simple replacing original with aftermarket ignition coil. However external shape of the product usually is very similar to the original one internal design is of SMP design standard based on history of more than 30 years of coil manufacturing as well as analysis of failure modes of original coils.

TRiZ examples presented in this paper shows how use of simple innovative tools can support solving of problems and lead to changing design standards.

Keywords: Ignition Coil, Reverse Engineering

1. TRiZ history at SMP Poland Sp. Z o.o.

1.1. TRiZ Awareness at SMP Poland

SMP Poland has started first dry type ignition coil in 1983 and through the years has delivered products to both OE as well as Aftermarket Customers. SMP main goal is to have product with OE or OE exceeding quality at reasonable price. Through the years also ignition coils have changed design starting with traditional type, through multi output and rail types into plug on top and pencil coil types. Main drivers to the coil shape are the limited space available in the engine compartment, as well as higher electrical output characteristics due to the higher compression fuel mixture within the engine cylinder. Also modern ignition coils have electronic driver module implemented into the coil what also increase complexity of the coil design.

Continues changes to the coil design result almost in never-ending update of the Design Standard Document and some of the failure modes have not been noticed before and right solution need to be found still. Also analysis of the OE original coils returned from the marked shows that failure modes are linked with the design as such and if design is not changed those would be also implemented into the Aftermarket product.

We have heard of TRiZ success stories in the automotive, aerospace as well as electronic industry, but majority of those articles were linked to the new products as well as the improvement of the existing product improving the product functionality. In our case we have limited scope so the external shape and output electrical parameters are as per the original specification and only factor which we can improve is the product cost and robustness.

1.2. Training and the Pilot Project

TRiZ training in Poland has not been easy to find, till 2015 only TQMsoft [1] carried out "TRiZ Basics" in Polish language. Two engineers have joined this training in 2014 but examples and theory presented was not fully understood by our engineers. Also problem was that the training covers almost all of the TRiZ tools what within the three day long course is difficult to accommodate. After the training we have looked to one of our design problem but really we have struggled to get the right tools and right approach so the problem remained not solved, at least not with the usage of TRiZ tools.

So when in 2015 ODiTK has started the TRiZ workshop and training program called "TRiZ Marathon" we decided to give the second chance and have sent our engineers to the first two workshops. Advantage of such workshop is that not only we have learned very few but basic TRiZ tools but also we have got workshop with our real problems to solve. During the first workshop we have decided to select the first pilot project. Our learning point from the first approach was that we should not look into the one for the product under the design but use the tools to solve one with existing product and we have selected product which were designed not by our design center but product manufacturing center has been moved to SMP Poland. As the input materials we have used templates and materials by Karen Gadd [2]

2. Pilot Projects

2.1. Project selection

1. Ignition coil is kind of the electrical transformer transforming through the electromagnetic field energy supplied by primary coil with the low voltage into the high voltage and the secondary winding. Initial energy is supplied by battery with low voltage 6-14 V and relatively high current 6-13A, output characteristics are high voltage 12-30 kV and 30-120 mJ spark energy. Efficiency of the coil should be greater than 45%. Ignition coil fails when we have electrical breakdown within the coils resulting in low or no output voltage. Ignition coil consists of the primary and secondary coils , metal lamination, plastic housing, bobbins, metal connectors and is filled with bisphenol type epoxy system under vacuum conditions.

2. Because of the gear from 12V up to 30kV secondary winding is of the thin wire with the diameter 0,05 mm range. Usually with the proper coil design and winding distribution electrical breakdown within the coil is not the problem, but due to the difference in the thermal expansion between the coil components, mainly epoxy system and metal lamination. Ignition coil works within the engine compartment, and nowadays is placed even within the cylinder block and is exposed to vibrations and high temperature stress especially in the winter conditions. With such rapid temperature gradient epoxy has tendency to crack and damage the electrical connection or allow moisture to get into the coil causing the electrical malfunction.

3. 6P is six output coil for Chrysler Dodge and Jeep popular application main problem with this coil is large epoxy content over the metal lamination. While validation testing main problem was the epoxy cracking.

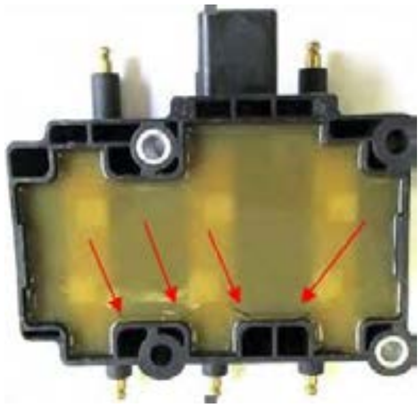

Fig. 1. 6P Ignition coil with cracks after the temperature shock tests

Coils has been exposed to the temperature shock test with the changes from -30 degC up to 115 degC. Cracking has been appearing randomly after few or more temperature cycles.

Original protection were plastic covers (male and female parts) assembled over the laminations and separating metal from epoxy system.

Fig. 2. Plastic covers securing the metal lamination

4. With support of ODiTK trainer we have run the brainstorm session with the team of experienced and fresh mechanical designers as well as electrical engineers. We have decided to use "bad solution park" as well as "innovative contradiction" tools [2] provided by ODiTK. Within the session we have determined that the main contradictions to solve are :

14: Strength – 12: Shape

27: Reliability – 12: Shape

And the solutions which we have selected to work on are:

10: Preliminary action,

11: Beforehand cushioning

30: Flexible shells and thin films

40: Composite materials.

5. As the result of the session, our mechanical design team has proposed use of the elastomer over mold instead of the plastic shells. Injection mold was neither expensive nor complex to make and after 8 weeks we have been able to run side by side, existing and improved coils validation. Results of validation test pls find presented in Tab. 1. Problem has been solved completely.

Table. 1.

Validation test result for 6P coils.

Coils description	Qty	Test result
Coils with plastic covers	30	24pcs. – cracks
Coils with elastomer	30	No cracks

Beside improved quality we have also eliminated 50% of the molding cycles, instead of molding female and male part of the shell we have just one over molding cycle with elastomer. Cost of elastomer material is higher than for the plastic resin but we have applied just the thin layer so overall cost per one coil has been reduced. Coil over mold with elastomer next has been implemented into the SMP Coil Design Standard.

2.2. 6P no connection problem

1. one of the potential weak point in the coil design are joints between copper windings and metal output/input terminals. Usually used technologies are soldering and different types of welding, but the most cost effective one is mechanical connection either by sliding in wire into the metal terminal or by applying threated terminal. Our selected solution was the cubic type terminals on PCB board. Coil pack with the terminals next has been pressed over the output terminals over mould in the plastic coil housing.

2. Problem appeared after coil epoxy potting and what we have noticed that the thin film of the epoxy has penetrated in between the HV output terminal and the corresponding cubical ones and insulated the output. What we have done before we decided to use TRiZ tools were the different terminal material selection and different shape of the HV output terminals with and without grooves, etc. Results of those trials were not conclusive and problem remains not solved.

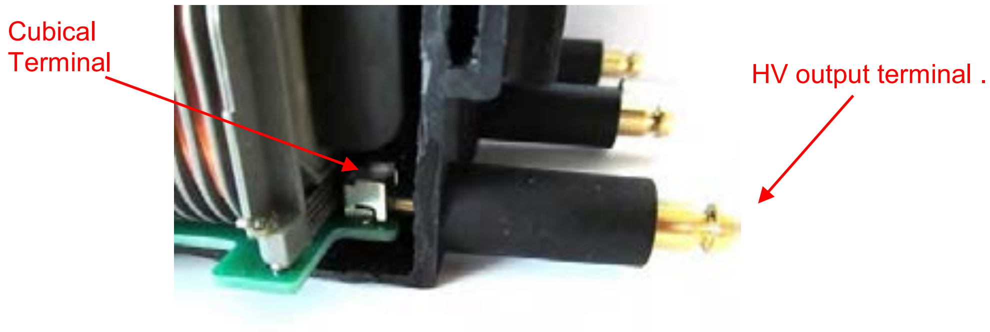

Fig.3. coil pack assembly

3. Our local TRiZ Leader has started the brainstorming session and “bad solution park” and in result we have noted that there were not to many contradictions.

10: Force (intensity) – 36: Device complexity

27: Reliability – 36: Device complexity

And out of the innovative solutions we have selected to work with 35: Parameter Change.

4. Parameter to change was the spring force of the cubical terminal, and ultimately we need just the tight connection remaining the same and stable through the whole manufacturing process. So we reduced the connection to just the simple spring with no space for epoxy to flow in between and interact with large metal wall surfaces of cubical terminal.

Fig. 4. New spring terminal

5. This solution we have managed to implement with no additional cost and final cost of the PCB with the terminal has decreased. We had two design iteration of spring terminal to allow its faster and better assembly into the PCB board but the main problem has been completely solved.

Tab. 2. End of Line test result for improved and existing terminal design for 6P coil

Coils description	Scrap
Coils with stamped terminal	35%
Coils with wire terminal	0%

2.3. Epoxy leaking problem

1. Ignition coil traditionally has been impregnated by oil but modern coils since 80' XX century are of so called "dry type" filled with epoxy system udder the vacuum conditions. Epoxy systems are with different mechanical and electrical parameters after curing, but they have one parameter in common, low viscosity while potting allowing good coil impregnation. Problem is when we have decoration caused by plastic processing of corresponding materials and then at the joint areas we may expect leakage. Unfortunately potting process is fully automatic so the outflow of the material cannot be noticed and such coil also cannot be reworked and need to be scrapped.

2. OE coil manufacturer has design the coil with o-ring sealing the HV bobbin and housing. We have accommodated the similar design and while the pilot production we experience 2,3% of scrap due to the epoxy leaking issue through the o-ring. We looked to the o-tring assembly

process but application of release agent as well as improving the o-ring design tool did not solve the problem, so we decided to look again into our design.

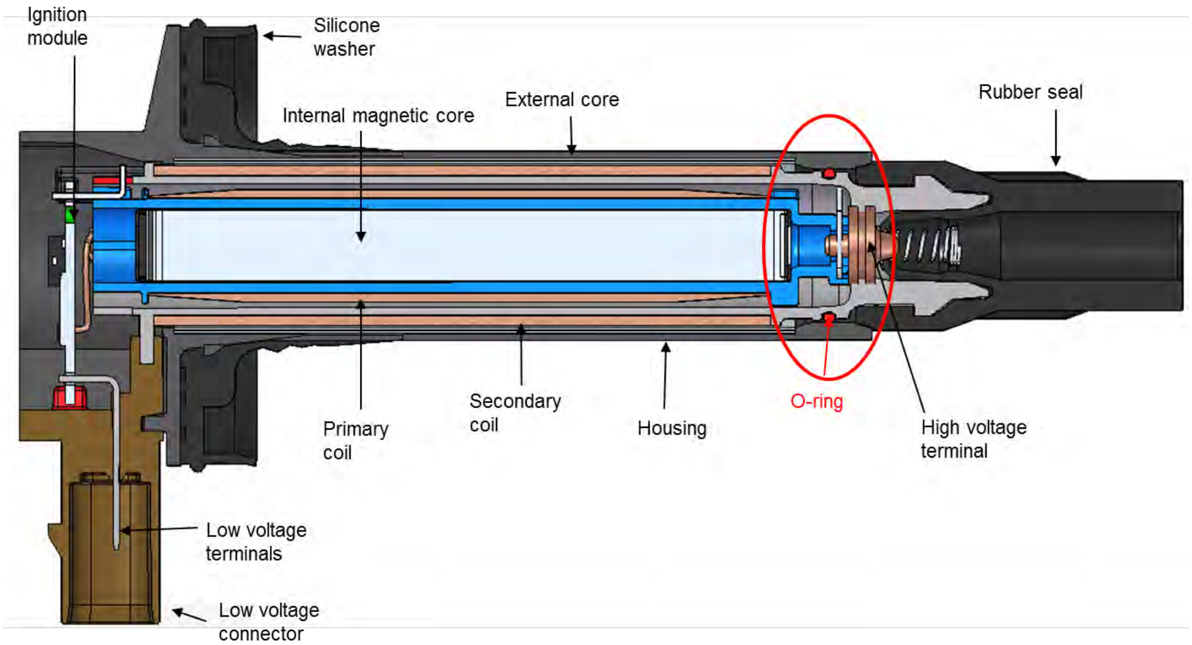

Fig. 5. Sketch of the OE coil design

3. Again we have used “bad solution park” and brainstorming, in result we have found that the main contradiction to solve are :

23: Loss of substance – 36: Device complexity

23: Loss of substance – 32: Ease of manufacture

And solutions were :

10: Preliminary Action ,

33: Homogeneity

Basically obvious was that we should remove the o-ring. We have changed the design to have a homogenous coil housing and have the connection between HV terminal and the HV bobbin inside the housing. Leaking are has been completely eliminated and again cost savings with removing o-ring.

Fig. 6. Improved design with no o-ring.

3. Project with New design

3.1. Make vs not make

Some of the aftermarket coils due to the high market demand resulted from the very bad initial original design already have been tolled and are manufactured by low cost suppliers. Those supplier simply copied the original coil design. With standard business approach we would not have our payback justified. We cannot change our investment cost so only area to look was the bill of the material and try to reduce manufacturing cost. Our decision was to go with TRiZ.

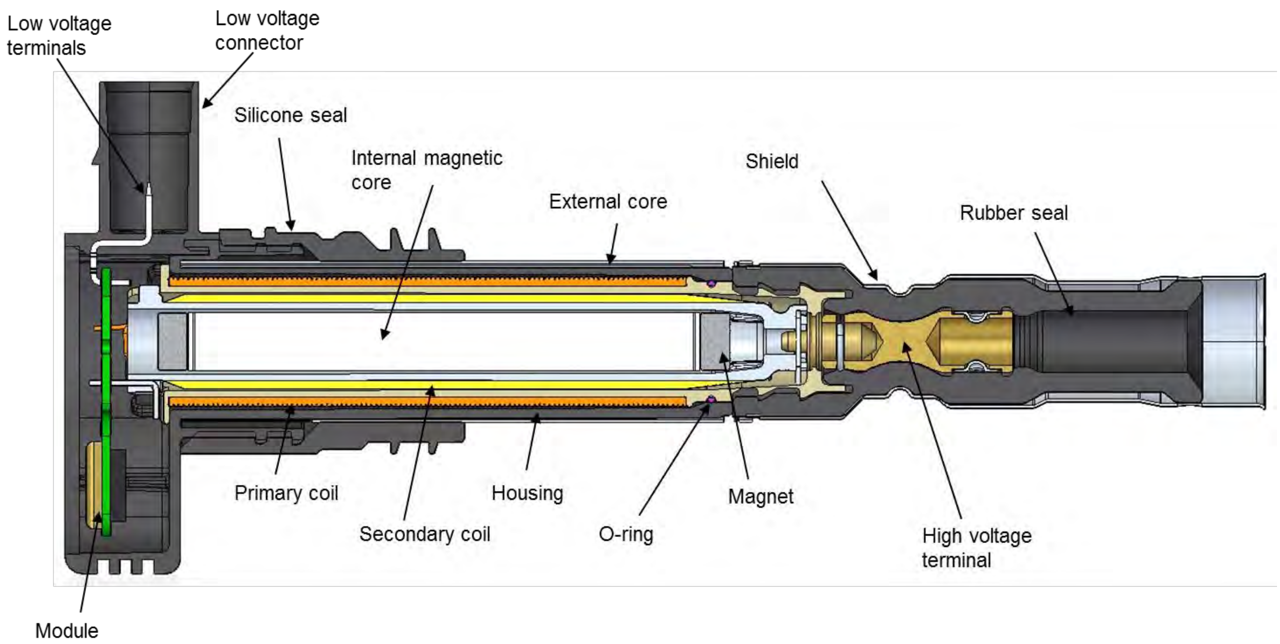

Fig. 7. Pencil Coil OE Design

3.2. Analysis and proposal of solution

So we decided to go with already very well understood tools like “bad solution park” and brainstorm. We have used the web tool as available on ODiTK web page [3] for those who attended the TRiZ Marathon.

So contradiction to solve we have found:

39: Productivity – 29: Manufacturing precision

39: Productivity – 32: Ease of manufacture

39: Productivity – 38: Extent of automation

And solutions were:

05: Merging

10: Preliminary Action

Decision was to decrease number of elements with keeping the same functions. Important was to keep the mechanical spring action between the HV terminals output and the spark plug to keep the same fitness function.

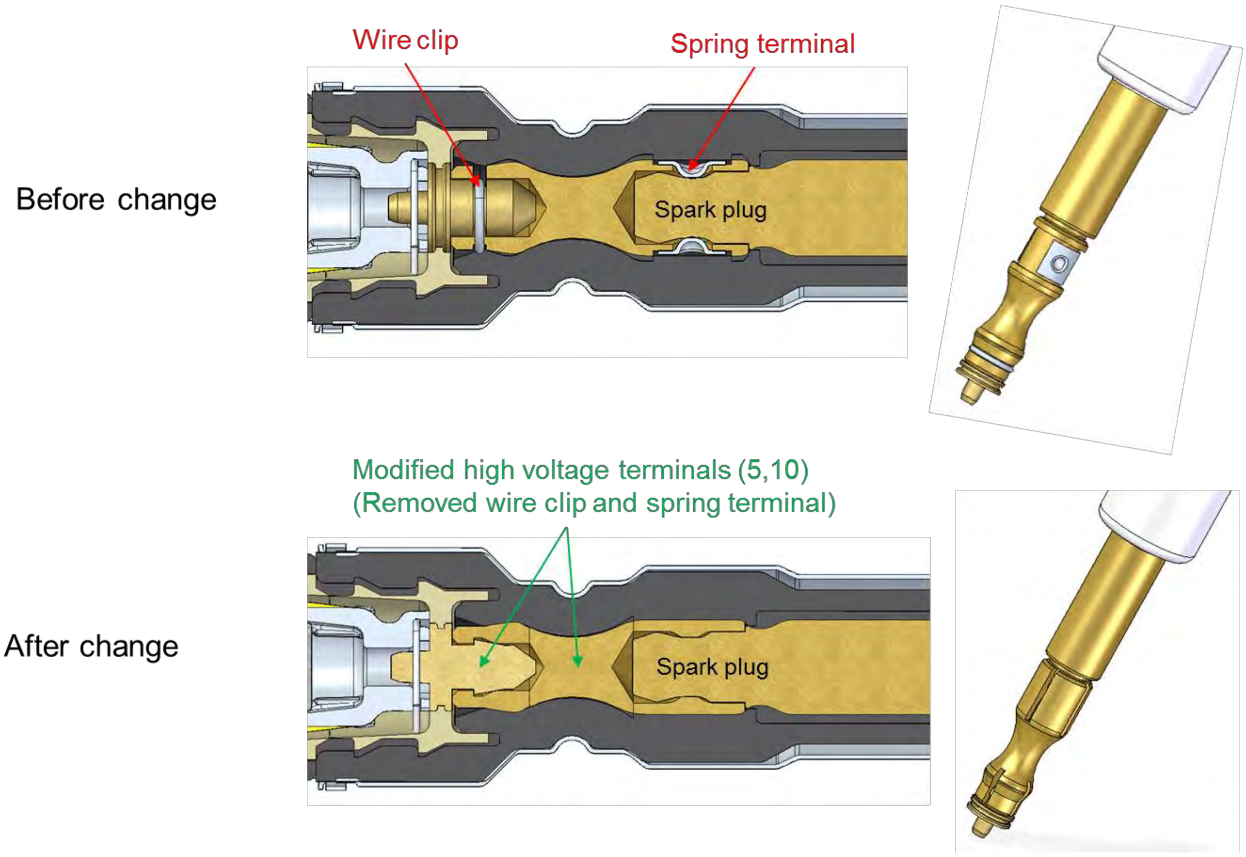

Fig. 8. Proposed solution

With the proposed solution we have reduced three elements and replaced them by just one what and no labour content to be spent while coil assembly so the total saving per product was 0,90 USD what has moved this coil to the area where starting production is profitable.

3. Conclusions

Like TRiZ solutions which looks very simple at the end our conclusions are also pretty much straight forward:

a) TRiZ basic tools and aftermarket product design is an ideal fit. Allows to break the paradigm of not invented here and move forward with the solutions of better cost and quality.

b) Try to use simple problem to solve, and preferably one where you are not the author of the design, this does not block your mind while analysing it and looking at the solution. Next it is easy to move to the new design and use the TRiZ tools to support the robustness of the product with involvement of the design team.

c) Do not think of all the problem at the same time, like functional problem and cost issues. Important is to find the ultimate final result first and next try to manage cost issues. Our experience is that applying the TRiZ results in some investments but with almost instant payback coming from easier and less material assembly not even mentioning cost of poor quality issues.

d) TRiZ is like disease, so instead of releasing within the whole company and department, best is to start with smaller group. Positive and immediate results will make the rest eager to learn and follow TRiZ methodology.

Acknowledgements

We would like to thank Michał Hałas, TRiZ Champion and Trainer at ODiTK, for his help and support during TRiZ implementation within SMP Poland..

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TRIZ IMPLEMENTATION EXPERIENCE IN BASEL

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Abstract

TRIZ was introduced in RUSAL, EN+, Basel corporations owned by Oleg Deripaska, a famous Russian businessman, in November 2016. In 2016, the training was performed under outsourcing contracts with TRIZ experts.

In 2017, RUSAL, EN+, Basel created their own TRIZ departments. TRIZ experts were involved in the work of every department at the corporations as well as existing RUSAL, EN+ or Basel's employees responsible for implementation of TRIZ solutions and for interaction with departments of every corporation.

The following groups of different employees with different backgrounds were created: Trainers of Business System course, Graduates of Business System course, Aluminum Division, Engineering and Construction Division, Direction on Technical Issues, Alumina Division, Employees of Engineering – Technical Center, Department of Industry Development, Managing Group, New employees, Engineering group for Automobile Factory, Engineering group in Energy Sector, HR group, Agricultural Group, Insurance Group, Board of Directors.

Training courses consist of three modules, with breaks of 1-2 months between the modules. Duration of each module is three days, each day of 8 hours. The first module is introduction into TRIZ and explanation of the main tools, in the end of the module the students were invited to draft their personal tasks. After the first module, the students were given a homework – they had to use the TRIZ tools while working on their personal tasks.

During the second module - the students were requested to present the results of the homework, the trainers helped the students to complete their tasks and answered questions. Additional tools were explained. In the end of the second module, the students were asked to redraft their tasks into a project and to defend in the presence of their managers. The projects also underwent feasibility study. After the second module the break was 1-3 months, the students had to to put their projects into production. The third module – the results of implementation and obstacles were analyzed, new advanced TRIZ tools were explained.

The full course is 72 hours. All departments provided the lists of existing and prospective tasks. The tasks were distributed in clusters based on similarity. Some tasks were solved by students of the abovementioned groups; others were solved by TRIZ department experts.

Key words: TRIZ, TRIZ implementation, innovations

1. Introduction of TRIZ

1.1. Basel outline

Business of the Russian Federation is largely working now on introduction of TRIZ in practice. This kind of activity is initiated in various enterprises, in many diverse fields of work. The organizational set-up is most actively running in industries of the Basel group units.

Our industrial group involves about 100 Russian enterprises and a considerable number of entities in other countries. The scope of activities is rather large: energetics, metallurgy, mining, hotel business, agriculture and a variety of other branches. The complex of Basel enterprises is the largest employer in Russia – more than 250 thousand people are engaged in work for the group businesses.

Basel group comprises the leaders of the largest industrial branches, such as the leading global producer of aluminum RUSAL, the largest in Russia private producer of electrical power EUROSIBENERGO (enters En+ group), automobile holding company number one in Russia GAZ Group (enters Russian Machines Corporation).

Machine-building complex of Basel includes industries manufacturing cars, auto parts, aircrafts, carriages, road building and special vehicles. All of them are joined in the Russian Machines Corporation.

Industries of ore mining and smelting cycle included into RUSAL Complex produce 9% of aluminum made in the world.

Energy complex En+ generates considerable part of power used in Russia and in neighboring countries with ¾ of it coming from eco-friendly hydroelectric power stations of Krasnoyarsky, Bratsky, Ust-Ilimsky, Irkutsky HEPs and from many others hydro and heat stations.

The whole complex functions as one business – structure.

The Basel industries have clearly outlined development strategy oriented to growth and strengthening of leadership of the group units due to productivity enhancement, widening of industrial facilities, and realization of major innovation projects. Great attention is paid to green production security.

In due time the enterprises of Basel became the pioneers in introduction of the tools of productivity enhancement in Russia, they offered the manufacturing system based on the principles of Toyota Production System (TPS). Today Basel is an acknowledged leader in use of the Production System. The original Business-system is used now in the industries, it comprises not only improvement of own production, but firm work with raw material suppliers and product byers as well.

However, need of further growth of the production modernization makes search for new reserves. TRIZ has become such a base reserve for our enterprises.

1.2. TRIZ steps in Basel

Detailed inspection of the instrument efficiency went before TRIZ implementation in the units of Basel. The thing is that certain TRIZ enthusiasts – developers of new technics, technologists, managers used TRIZ tools long ago, but the tools were not determined as complex and systematically important for innovational development.

A few tasks from various spheres of the corporation business - from metallurgy to agriculture - were selected for the inspection.

The tasks being solved by the first trained group, there was organized the following round – one of the most complicated problems facing the holding units was forwarded for a solution. It was a matter of immature coal enrichment. The challenge to lower ash-content was complicated with a large number of conditions and limitations.

The problem was successfully solved by the working group and it was considered as an additional positive signal. Eventually the departments of TRIZ were created in the structures of RUSAL, Basel and En+. Overall direction of the complex was allotted to Sergey A. Yakovenko.

2. Work of TRIZ departments

2.1. Main tasks of TRIZ departments

The tasks of TRIZ departments are determined as a jump of efficiency and intensity, process improvement by the staff forces, and innovation activities in industries should be geared up for the tasks to be solved, as well as innovation creativity culture should be increased.

TRIZ departments in all of our industries are put up according to the same pattern. They include professional TRIZ specialists working on the staff training and tasks solving, and second staff of the enterprises. Their task is to control the implementation of the found solutions.

2.2. TRIZ technologies

Three technologies of the task solutions are used in work:

1. Solutions of tasks by the work groups in enterprises. Such work groups are formed of the most active and technically sophisticated specialists. They are trained in TRIZ. The education consists of three seminars 24 hours (3 full days) long each. Between the seminars there are breaks one or two months long. Totally the seminars last 72 hours. The trainees combine the training with solutions of actual tasks. Critical design review of the trainees is done after the second seminar close. The third seminar is for analysis of the secondary tasks emerging under an innovation introduction, and for the tools of prognostication. Thus, there were formed and trained ten groups of specialists with their total number of 385 persons.
2. Urgent solution of tasks. Urgent tasks are solved by the staff – TRIZ specialists, and subject manner specialists are also involved as experts. Such “urgent” tasks arise rather often; they may come from force-majeure events, for example, under repair works.

3. Planned solution of tasks non-related to a specific section of the work process. The tasks of that kind may be set by the enterprise key personnel and be involved in either technical or organizational and management aspects of work. Then the tasks are solved in a relatively tranquil regime, with the terms of work clear in advance and with the possibility to plan the work.

2.3. TRIZ task sources

The tasks are borrowed from different sources. Certain number of tasks is found out by the services of the Production System and Business System of the enterprises. These tasks were revealed but they were not solved by own forces without methodic support.

Another source of the tasks includes own analytical tools of TRIZ. Work on revealing of the tasks runs with the use of dataflow, functional, cause-and-effect analysis, functional-ideal modelling and so on.

2.4. Types of the projects in progress

The most often met tasks are those ones on improvement of work effectiveness of already existing systems – processing lines, devices, certain technical objects, management scheme, lowering of energy demands, as well as spend of other critical resources, improvement of product quality, reliability, safety, ecological compatibility.

Additionally, there are tasks:

- Revealing of real reasons of defects,
- Synthesis of new products,
- New variants of the object use,
- Achievement of a result under minimally allowed alterations in the system and in its environment,
- Long-range challenges – determination of the system own development limits,
- Predictions of market development
- Administrative tasks

At present time about hundred tasks are being worked out in three departments.

3. TRIZ training courses

3.1. Peculiarities of TRIZ in Basel

Specific character of different enterprises requires TRIZ specialists prompt structural adjustment of training courses and tools suggested in the first place. The department performs great work on training and solving of tasks.

The following groups of employees with different backgrounds were created:

Trainers of Business System course, Graduates of Business System course, Aluminum Division, Engineering and Construction Division, Direction on Technical Issues, Alumina Division, Employees of Engineering – Technical Center, Department of Industry Development, Managing Group, New employees, Engineering group for Automobile Factory, Engineering group in Energy Sector, HR group, Agricultural Group, Insurance Group, Board of Directors.

All departments provided the lists of existing and prospective tasks. The tasks were distributed in clusters on the basis of similarity.

Managers and supervisors, key specialists are considered as priority applicants for education.

3.2. Modules of training courses

A training course consists of three modules, with breaks of 1-2 months between the modules. Duration of each module is three days, each day of 8 hours.

The first module gives the introduction into TRIZ and explanation of main tools, in the end of the module the students should draft their personal tasks. After the first module the students receive a homework – they should use TRIZ tools when performing their personal tasks.

The second module – presentation of the homework results by the students, the trainers help the students to complete their tasks and answer questions. The trainers also explain additional tools at this stage. In the end of the second module the students have to redraft their tasks into a project and to defend in presence of their managers. Some tasks were solved by students of the abovementioned groups; others were solved by TRIZ experts.

The projects also underwent feasibility study. After the second module the break was 1-3 months, the students had to put their projects into production.

The third module is designed for analysis of the implementation process and of the obstacles emerging under the process, and for clarifications concerning new advanced TRIZ tools.

3.3. The tools used

The struggle between two trends may be observed now in TRIZ. One of them is directed to comprehensive simplification of TRIZ instruments and apparently tends to prompt solution of relatively simple tasks. Another one tends to make more difficult the set of instruments that should be used for work with advanced complex.

It must be admitted that certain merits and demerits are at each trend, and they both have profitable properties. However, for the base of the department work organization, the conception of “the complex instrument” was accepted as the base, the conception provides coverage of a large scope of tasks by means of selection of optimum combination of methodical tools.

Specialists of the departments work on strengthening and deepening of analytical and solving instruments:

- Analysis of customer values in processed and latent markets
- Analysis of flows
- Functional analysis
- Parameter analysis
- Description of the system limit state
- Functional-ideal modelling

- Trimming of the system elements
- Paradox as a mean of formation of the problem understanding field
- We are trying to build new variants of presentation of the system development limits allowing increase instrumentality and reliability of predictions
- We work with the variants of new presentations of contradictions and with instruments alternative to the contradictions, but built based on other principles
- We improve cause-to-effect analysis increasing its accuracy and creative force
- We look for new approaches to facilitation of resources finding in developing systems

4. Conclusion

We regenerate the work with expert groups acting in our institutes involved in applied researches, establish communications with research groups in Universities, and draw students to work on task solutions and on accumulation of new chemical, physical data needed by practicians. In particular, this work is done with the students of the Physical Departments of Moscow State University, Moscow Institute of Steel and Alloys and in certain other Universities.

Variety of conditions wherein our specialists work, width of challenges forwarded by them require notable performance from our TRIZ specialists on TRIZ instruments adaptation.

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TRIZ IN INDIA AND ITS APPLICATIONS IN TECHNICAL INNOVATION

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Abstract

With a clear emphasis to bring innovation into forefront, the Government of India is promoting Innovation through various initiatives like: Make in India [1], Digital India [2] and Start-up India [3]. In the context of changing super system, a genuine need for 1.25 billion Indians is to grow through Product and Process innovation. In this paper, the author would bring out how TRIZ is being deployed in India and used for enhancing Technical Innovations in Indian industries as a new problem-solving tool. Further TRIZ is enabling to move one step ahead of the curve to make inventions happen in India. The paper highlights how the professional bodies (Corporate, MSME, Start-up incubators) and Academia are engaged in this change with a focus to create not just Intellectual Property (IP), but develop 'Quality IP'.

Any change is successful if there is a Pull or a shared need established. In this context, the shared need within the Indian industries is to have a differentiated product and a method that enables the need. This paper emphasises on various ways of establishing this shared need that are designed, tested and adopted by ATTI [5] addressing Indian industries, Micro-Small-Medium-Enterprises (MSME) and Academia. Many strategic actions were taken to build a shared need like organizing – India's MA TRIZ conferences, TRIZ certification workshops (levels 1 & 2), TRIZ introductory talks by ATTI and other MA TRIZ Associations in India.

The back bone of Indian industry is MSME. One way to grow the MSME is to increase exports by developing differentiated products. Many invited talks were conducted with consortiums of MSME segments and conducted multiple TRIZ level 1 workshops.

Every year, India graduates about 1.7 million engineers. The ability of an under-graduate engineer to be an entrepreneur varies based on the exposure and is a function of institute that they graduate from. The need is to engage the Academia (faculty and students), inspire them to learn new ways of problem solving. As per the strategic actions mentioned in this paper, many TRIZ awareness sessions were conducted across multiple engineering colleges and universities in this regard. MA TRIZ President, Dr. Sergei Ikovenko gave inspired talks at engineering colleges on TRIZ in India, which was much appreciated.

Keywords: TRIZ, India, Invent in India ™, Bharat TRIZutsav ™

1. Introduction

In many ways Innovation in India is associated with Jugaad. Jugaad[5] (alternatively Juggaar) is a colloquial Hindi word, which has various meanings depending on the situation. It could also refer to an innovative fix or a simple work-around, a solution that bends the rules, or a resource that can be used in such a way. It is also often used to signify creativity - to make existing things work, or to create new things with meagre resources. As per Oxford dictionaries [6], Jugaad: A flexible approach to problem-solving that uses limited resources in an innovative way. 'countries around the world are beginning to adopt jugaad in order to maximize resources'. Unfortunately, Jugaad is a trail and error approach and is not structured and hence it is not repeatable and reproducible, in other words it is not predictable.

TRIZ deployment in India at a corporate level was started in John F. Welch Technology Center (JFWTC) that houses GE Global Research Center (GRC) and in engineering division of GE Energy business that is co-located in JFWTC in late 2000's as a corporate initiative to enhance the Design for Six Sigma framework (used in product design). Being a global company with a strong vision, the global centres were also empowered to learn along with the core team in Niskayuna in various levels of TRIZ. With 4 members certified in level 3 from JFWTC, Bangalore in 2011, the TRIZ penetration started in JFWTC and GE Energy business with multiple patents filed from Bengaluru through TRIZ workshops. The author was a GE Energy employee and led a culture change of Technical Innovation at Engineering division of GE Energy business in Bangalore.

In India, TRIZ was taught at Indian Institute of Technology, Mumbai (IITB) by Professor Prakash R Apte, and certification workshops are conducted by ProInn Consultancy® [7] in association with ATTI and TRIZ Association of Asia [8]. TRIZ conferences were organized by various entities in India. In 2010 TRIZ Innovation India [9] had their conference "TRIZ India Summit". There was no further activity as a national conference since then. "TRIZ Trends" organized by GE JFTWC in 2014 and 2016 focused on recent trends in TRIZ. "InnovEx Asia" organized by TRIZ Association of Asia in 2015 and 2016 with a focus on Innovation. The apparent gap that was found in 2015 in India: No national platform that is TRIZ focused and consistent year on year in conferences by a non-profit organization, not open for all, only few pockets of penetration of TRIZ in academia and lack of TRIZ mentors.

2. ATTI formation

With the advent of author relocated to Malaysia to work with GE Aviation, Dr. Sergei Ikovenko, TRIZ Master and President MA TRIZ connected him to the larger TRIZ community in Malaysia. The MyTRIZ (Malaysia TRIZ) Association, enabled an exposure that was quite outward at a national level.

The larger changes in the super system (in India) came with an emphasis by the Government of India to "Make in India" gave right impetus to the manufacturing sector. In its' true spirit, Make in India needs "inventions to happen in India" and this is an additional gap to be filled. With the need for inventions to happen in India and to address all gaps identified above, Association for TRIZ and Technical Innovation, ATTI was formed in Sept. 2015 by a team of professionals and scientists who believed in power of TRIZ and its' deployment in India. As a measure of effectiveness, a mission to mentor 5000 inventors by 2020 through TRIZ was initiated by ATTI alone. ATTI is a not for profit organization with a focus to contribute towards TRIZ and Technical Innovation enhancement in India.

The three-fold strategies adopted by ATTI towards this change is across three verticals of Corporate, MSME & Start-ups and Academia is not just training the people on TRIZ but to mentor skilled innovators in various industries.

1. Iccha (in Sanskrit is to inspire)

2. Gnana (in Sanskrit is to Empower with knowledge)

3. Kriya (in Sanskrit is to execute)

All the activities adopted by ATTI, are in this direction.

3. ATTI strategies

1. Inspire people to invent at a national level awareness session using TRIZ. Inspiration is always drawn by giving right exposure to the people on what they thought can't be done and show how to through case studies. Another way of inspiring people is to put huge goals that look impossible at the beginning, but accomplished with a focused effort. Bharat TRIZutsav™, India's MA TRIZ conference and to groom 5000 inventors by 2020.

2. Empower with knowledge through new skillset learning. Knowledge of just problem solving is not sufficient. It is required to understand the nuances of the product development and the business side of the product. TRIZ certification workshops were focused on actual problem solving critical to the business needs.

3. Execution support by mentoring and change management to accelerate cultural change that supports technical innovation and contribute to the learning of TRIZ knowledge to other TRIZ Associations. Execution is a function of leadership traits like Inclusiveness, perseverance and collaboration. IP is for the business, but the generators are people. So the entire workshops were organized such that the hands on practice from diverse teams is encouraged. Mentoring post TRIZ workshops based on the interest of the people that enables learning to practical application.

3.1. Strategy #1: Building awareness pan India

Change is effective when it brings a pull in the system. The pull should come from industry (Corporate and MSME) that demands a new skillset needed for its' growth after experiencing tangible results on technical innovation using TRIZ. Once demonstrated this skillset would be expected from academia while hiring.

Many introductory talks were conducted across multiple business verticals including: Inhouse TRIZ awareness sessions in large corporates pan India; Seminars organized by Ministry of Micro, Small & Medium Enterprise (MSME) and Consortium of MSME's; IP conferences; and educational institutes in various states of India like Karnataka, Tamilnadu and Gujarat.

A critical aspect of awareness is to share consistently success stories to professionals who want to be inventors. Adopting TRIZfest and customizing to Indian culture, "Bharat TRIZutsav™" evolved. Bharat TRIZutsav™ is a national platform to showcase benefits of TRIZ application in industries through case studies, share new knowledge by bringing in national & international speakers on TRIZ and importantly motivate the young and mature minds alike to Invent.

Bharat TRIZutsav™ has 4 important awareness sessions each year.

1. Give international exposure on latest development in TRIZ by TRIZ Master(s)
2. Bring CTO's of large corporate to share how they drive Innovation
3. Inspire people with real case studies of TRIZ application and its' benefits
4. Share tactical and strategic practices of technology leaders how they empower their teams while building a culture of Technical Innovation.

Bharat TRIZutsav™ 2016 was the 1st MA TRIZ conference in India where the industries from multiple verticals like: Automobile, Power Generation, Oil & Gas, Polymers, Heavy engineering, Pharmaceuticals, FMCG participated along with MSME and Academia. It also witnessed keynote talk by Dr. Sergei Ikovenko, TRIZ Master and MA TRIZ President, and many TRIZ level 3 professionals in India.

Any organization can be classified into two groups. One enablers (leaders and managers) and other executors (who work hands-on in problem solving). To inspire the executors the key is to inspire the enablers how to create an environment that simulates the later. With this focus, a panel discussion was themed on "How to groom Technology leaders with a skillset of technical innovation".

Fig 1. Group photo of Bharat TRIZutsav™ 2016

With a great demand from the industry and professional bodies, Bharat TRIZutsav™ 2017 was organized on 3rd August at Bangalore. The keynote talk was on latest TRIZ trends by Dr. Sergei Ikovenko, TRIZ Master and MA TRIZ President, CTO talk was by Group Chief Technology Officer of Tata Sons Limited. The TRIZ case studies came from diverse industries like: Power distribution, Healthcare, Consumer electronics, Agriculture, Power generation and Automobiles and were presented by TRIZ level 1 and 3 MA TRIZ certified professionals on below 5 axis of technical innovation.

1. Reduce product cost
2. Reduce product harm
3. Increase product performance
4. Increase product reliability
5. Simplify product

A panel discussion was focused on "How technology leaders empower their teams to Invent". Participated by Industry leaders from diverse corporate world in India. Many professional bodies were partnered with Bharat TRIZutsav™ 2017 like International Society of Automation, ISA, Society of Automobile Engineers, SAE and this would increase as we move towards 2018 and beyond.

Fig 2. Group photo of Bharat TRIZutsav™ 2017

Now, at national level, India, Bharat TRIZutsav™ is serving the purpose of bringing new knowledge to the country through showcasing the TRIZ success stories, new trends in TRIZ through keynote talks by TRIZ Masters, Technology leader, CTO's keynote talk from reputed firms and ways to build an environment of technical Innovation in an organization.

3.2. Strategy #2: Empower with Knowledge

Change happens only when concrete examples are demonstrated consistently over a period. With a clear intent to bring pull in the country from the Industry and professional bodies, the only way is through conducting hands-on problem-solving workshops with tangible results.

To enable the above change, the adopted strategy is a top-down approach, very similar as adopted in large corporates that successfully deployed TRIZ, like GE GRC. These workshops were attended by people from various levels in an organization top down and hence effective participation was ensured. In one of the such organization in India, many chief scientists were trained and certified in both level 1 and level 2.

As adults, the best way one can learn is through embrace adult learning techniques. Best of the adult learning techniques is by experiential methods and the most proven of them is by solving tough problems that people couldn't solve earlier. In the last 2 years, 12 MA TRIZ certification workshops were conducted in which major corporations participated pan India. The benefits from these workshops range from many patents filed to significant product cost reduction in multiple concept development.

Few companies embraced higher levels of TRIZ through level 2 workshops, conducted by Dr. Sergei Ikovenko and supported by the author. Two such workshops were conducted since 2016.

Two non-certification workshops were conducted to MSME segment where product cost reduction being a major necessity to make them competitive. The most appreciated tools that were adopted in problem diagnostics include: Functional modelling, cause and effect chain analysis, product Trimming, and in problem solving the Function oriented search along with technical and physical contradictions solving. This follow the level 1 curriculum of MA TRIZ [10]

Interestingly, for start-ups, where the growth enabler is by offering a product / service at a fraction of cost or with new value creation can be differentiated effectively by embracing TRIZ.

In 2017-20, we would expect more engagement with start-ups and academia. Instead of teaching / giving basic awareness of innovation, methods to Invent would be provided to students. The plan is to bring TRIZ into academic curriculum in deemed universities. Focus is to train the faculty so that it would be useful in their research, in guiding PhD students, teaching new ways to invent to graduate and post-graduate students and move towards grooming inventors in India.

3.3. Strategy #3: Execution through changing mindsets

The most critical aspect of any new learning is its's retention. The context of "execution" ensures that the baby steps of new learning are taken with right support through mentoring. Learning to identify Psychological Inertia, is a big change by itself that the TRIZ workshop participants experience. At an organizational level, this demands change management to transform the culture from unpredictability to predictability in time bound novel solutions.

Growth for embracing TRIZ by the Indian industry is not just the number of people trained. Rather build an eco-system that encourages retention of new learning by developing multiple mentors pan India. ATTI would be contributing significantly in this endeavour pan India through the TRIZ mentor program. A team of interested level 2 professionals is being groomed with this intent. In 2018, we would have a level 3 certification workshop and multiple level 2 workshops.

Knowledge is the only thing that grows by giving. ATTI has made few contributions in this regard. Participated and presented Keynote talks at PESTA TRIZ in 2015 & 2016 and at the 3rd International Report Conference in Liaoning Province with regard to Innovation method in Sept. 2016 that was sponsored by Innovation Method Society of Liaoning Province.

4. TRIZ service providers in India

There are two service providers that conduct MA TRIZ certification workshops in India.

1. ProInn Consultancy® in association with ATTI
2. TRIZ Association of Asia
3. TRIZ training by BMGI [11]

5. Conclusions

TRIZ in India is going to accelerate in an exponential manner. The Indian industry leaders are very keen to adopt TRIZ as a means of structured Innovation that can help bring new thinking on how to Invent. The critical factors are: multiple industry case studies, conferences like Bharat TRIZutsav™ that promotes national inspiration and building mentors who demonstrated results and understanding of TRIZ methodology. Leaders arise when need demands. In this context, ATTI, one of the youngest of all the Associations of MA TRIZ along with fellow MA TRIZ organizations in India, TRIZ professionals in India and around the world will create a big impact towards imparting structured inventive thinking to the Indian professionals.

We expect to have many faculty and students trained, apply their learning on actual problems that surround them in their locality and bring wow solutions to the community where they leave. This will also help the budding engineering graduates to deliver tangible results in technical problem solving to the corporate or MSME or Start-up once they complete their degree.

In the past year of ATTI's inception, we made a strong foundation to a large purpose, transform thinking towards inventions happening in India using TRIZ with toolkit that "empowers everyone to invent™". Being goal focused, the charter is to provide right learning of various levels of TRIZ certifications, and mentor them such that they become the promoters of this new learning to a larger group and build in a ripple effect of multiplying multi-fold each year. The bottom line is to educate and inspire "young and mature minds to Invent" and to "Invent in India™"

The workshops are building lots of curiosity among the Engineering professionals, Scientists, IP professionals to dare to think towards inventions and strengthen "Make in India", an initiative by Government of India. The country will raise to the occasion with many new inventions inspired by TRIZ and its application in Indian industry in years to come. The small mission of grooming 5000 inventors by 2020 by ATTI will surpass multi-fold and will bring predictability in novel thinking and increase multi-fold every year, both on its penetration and tangible results.

Many patents are being filed and in are process across the industry who undergone TRIZ learning and this trend will go multi-fold in years to come.

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TRIZ IN THE CONTEXT OF DIGITALISATION AND DIGITAL TRANSFORMATION

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Abstract

Today rapidly developing information technologies create unprecedented possibilities for intelligent, highly customizable products, increasingly efficient workflows and streamlined, highly automated production processes. Buzzwords like Industry 4.0, Digitalisation, Digital Transformation, Big Data and Internet of Things dominate the media.

Within this context we face the question if the Theory of Inventive Problem Solving can be applied to these new topics and if a methodology that was founded over 60 years ago could help solve challenges related to current information technology.

This paper will establish a view on above mentioned topics through the eyes of TRIZ and investigate if and how certain TRIZ tools and concepts can be applied to uncover potential for digitalisation and assist a systematic digital transformation process. Among other aspects, the authors will refer to a modified view on the Law of System Completeness together with a customized Function Model to optimize information flows for digitalisation.

Keywords: Industry 4.0, Digital Transformation, Digitalisation, Smart Systems

1. Terms and Definitions - "Buzzwords everywhere…"

Among TRIZ users current revolutionary changes with respect to technology, industries, communities and markets (often described as "digital transformation"), should not come too surprisingly. A lot of what is happening in the world of technology is completely in line with a multitude of fundamental TRIZ findings. And with TRIZ being a science describing the evolution of engineering or, on a broader definition, men-made systems, this should be expected.

Before assessing the applicability for TRIZ with regards to digitalisation the authors would like to clarify some terms that shed some light on the topics that are relevant for the digital transformation process.

The term "Digitalisation" describes the change of objects, processes and events caused by increasing use of digital devices. This includes creation of digital representations of physical objects (e.g. "digital twins"), events or analog media as well as the shift towards digital processes by means of information- and communication technology [1,2].

The increasing use of digital technologies causes an ongoing change process in the society and enterprises, named “Digital Transformation”.

Digital Transformation is enabled by:

- Digital Infrastructure like networks and hardware,

- Software/Applications and

- Business models and value creation networks.

Actors in the Digital Transformation Process are companies/enterprises, individuals, communities, science and the state. One of the main driving forces pressing companies to adopt digital technologies is the expectation of individuals towards companies. They expect current companies to be present on the main social media channels for communication, but also to shorten production time (and thus delivery time) and being able to offer customized and customizable products for individual needs and tastes [3,4].

In order to fulfil these expectations, companies themselves are working towards exploitation of the potential of current digital technologies and extended connectivity. Thus, several states and countries issued programs to make companies fit for the “digital transformation”. One of those programs is the German “Industry 4.0” initiative. The term was created to describe an imminent “fourth industrial revolution”, at the end of which production processes are self-organized by means of intelligent and digitally connected systems and there is direct cooperation and communication between humans, machines, facilities, logistics and products covering the whole product lifecycle. The benefits of this intended changes are expected to be the optimization of the complete value generation chain, decreasing production time by self-optimization, -configuration, -diagnosis and cognition and ability for mass customization and individualization (ultimately “batch-size 1”).

Within the Industry 4.0 framework several other terms were created for technologies that are required to work towards / create the “4th industrial revolution”:

Cyber Physical Systems (CPS):

Combination of IT and Software with mechanical and electronic parts that are then connected with each other via a network, thus being

Embedded Systems:

Computers that are embedded in complex technical contexts like monitoring, supervision and control.

Those CPS should be mainly independent and autonomous to decide upon required action to keep a system functioning. Artificial intelligence and machine learning also play a major role here [5,6].

In this context the term “Internet of Things“ (IoT) can be found which describes the ongoing connection of (physical and virtual) things that are capable of being identified and integrated into communication networks. The IoT allows objects to be sensed or controlled remotely across existing network infrastructure [7].

With this increasing number of devices, there is an exploding amount of data (Big Data) that are too complex, short lived and weakly structured to be evaluated by common methods of data processing. Already new methods are being developed to make sense of the amount of data available within the increasingly digitalized world [8].

It is obvious that the availability of an increasing number of connected digital devices with their sensors and applications create enormous potential for new business opportunities and business models. There is a huge technology push through e.g. smartphones, sensor technology, networks and increasingly intelligent software, which itself is creating a market pull when customers demand access to the unrestricted benefits of today's technology.

2. The Trends of Engineering Systems Evolution – "It is all in there!"

Despite all these new words, terms, categorizations and classifications, current developments are already described in one of the most basic building blocks of the Theory of Inventive Problem Solving: The Trends of Engineering System Evolution (TESE). Genrich Altshuller started formulating repeating patterns and characteristics describing the evolution of engineering systems (ES) starting in 1969 that since then have been reformulated, restructured and expanded by several scientists [9, 10,11]. Referencing the system of Trends currently taught by MATRIZ, several if not all laws describe the above mentioned topics quite well [12]:

Law of increasing Ideality – The general law of ES Evolution. The quotient of benefits and harm / cost increases, basically meaning that things will get better.

Trend of increasing completeness of system components and, as a prerequisite, the

Trend of increasing elimination of human involvement – these laws are in line with the intent to make the CPS autonomous and increasingly intelligent, decoupling human beings from needing to interfere. ES can make more and more autonomous decisions depending on the conditions, being increasingly able to learn and adjust themselves autonomously to cope with changing environmental influences. One of the ways to achieve this is also the IoT, so ES need to feature all the necessary components to be able to communicate.

Trend of transition to Supersystem – Diverse systems increasingly get interconnected, forming the IoT and sharing information with each other.

Trend of increasing degree of Trimming – As described in [13] ES increasingly get rid of components like control systems, transferring their related functions to Supersystem components. Increasing use of cloud computing can also be seen as one manifestation of this trend.

The trend of increasing flow optimization – This is probably the trend that holds the most potential for actively working on digitalisation. As a fundamental requirement, the unobstructed flow of information is crucial for an efficient digital transformation process.

Trend of increasing coordination – Obviously this trend (and it's subtrends) sums up the efforts in building embedded systems and coordinate activities across ES.

In addition, there are already several works that describe new laws and trends that take into account these changes in technology [9,11]

Interestingly, the topic of Digital Transformation seems to be represented by almost all Trends. To the authors this is a strong indicator for the essential nature of the changes made possible by todays technological advances.

Note: The authors decisively chose the expression "changes made possible" over "changes happening", as they are strongly convinced that change is not "happening", it is rather purposefully "made" by individuals or companies that exploit current technological possibilities to drive development, creating new solutions.

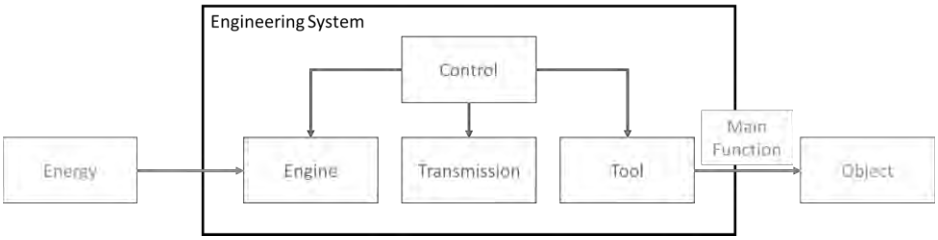
Consequently, to uncover potential for digital transformation the TESE provide excellent opportunities. Working through the mechanisms and tools for each trend will bring up a lot of possible directions how to advance products, processes and services in terms of digitalisation. The authors would like to emphasize the huge potential of flow analysis with an exhaustive set of recommendations on how to improve useful flows and how to eliminate harmful flows. If applied to the flow of information this TRIZ tool is a powerful method for improving processes and products with respect to digitalisation.

3. A minimally workable "Smart" Engineering System

As a prerequisite, the authors suggest to use a modified version of the existing model of a minimally workable engineering system described in the "Law of Increasing Completeness of System Components" when working on digitalisation. In digitalisation, we fundamentally deal with generation, exchange and evaluation of information. Per Definition, information is the amount of knowledge that is transferred from a sender to a receiver in form of signals using a medium (=channel) to perform a task (=function) or stimulate fantasy.

For IoT, CPS and embedded systems information is a necessary, essential asset. To define a minimally workable system that can function in a digitalized environment the addition of an interface as a necessary component is mandatory [see also 15]. This interface is specifically responsible for receiving information from and sending information to Supersystems. Consequently, the interface consists of receivers/sensors to gather information and senders/transmitters to send information (see Fig. 1). The control unit then has the task, to evaluate all information to adjust how the tool operates to fulfil the required function effectively, ultimately with increasing intelligence and ability to perform autonomously (AI, Machine Learning).

a.)



b.)

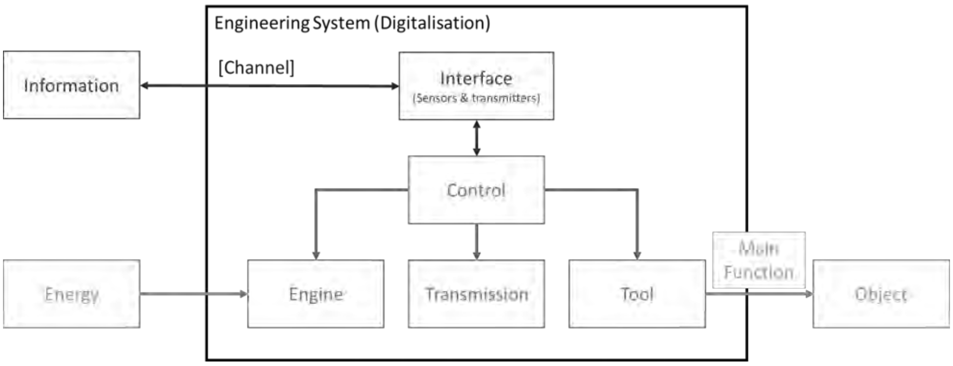


Fig. 1. General TRIZ representation of ES (a), modified representation for digitalisation context (b)

4. "Information" in Function Models

While the usual representation of a minimally workable ES seems to describe an ES as a means to convert energy in a coordinated way that is ultimately used to perform a function, the modified model suggests a representation of an ES that can act as a (ideally autonomous) adaptive control system with feedback loops. This can as well be depicted as a general function model:

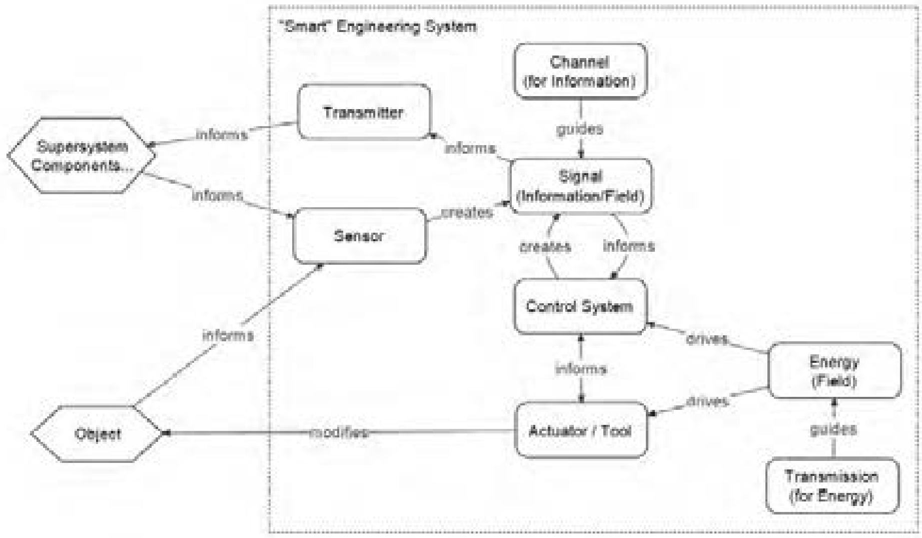


Fig. 2. General Function Model of a "Smart" Engineering System

With this general function model, it is easy to check if the concrete system under investigation is having all required components. For this task, it is not mandatory that the system has all components built in, maybe some necessary tasks (especially control-tasks, see [13]) are already transferred or transferable to Supersystem components. Especially consumer products like Smartphones with voice recognition, Amazon Echo, Google Home or Apple HomePod themselves represent interfaces to numerous higher-level digital engineering systems (logistics services, home appliances etc.). Moreover, to be in line with the Trend of decreasing human involvement, all tasks that need to be performed by a human being should be analyzed for potential to be transferred to ES.

As stated above, information is the transfer of knowledge, so by the function "A informs B", knowledge within component A is transferred (or shared) with component B. If the amount of knowledge within a component is considered as a parameter of this component, then the parameter changed within component B is the amount of knowledge, making it viable for a correct representation of a function.

When representing information in a function model as shown above, usually a limited formulation like "<component> informs <component>" is used. For practical reasons, the authors recommend specifying the concrete type of information that is transferred in greater detail. Similar suggestions have already been described for function models for software development by [14]. A general function "informs" can consequently split into several types of information that is shared between components (informs about orientation, weight, shape, temperature etc.). This procedure ensures that the type of information currently flowing in, through and out of a system can be accurately captured. [14]. The function analysis for processes can be used accordingly to assess processes in context of digitalisation.

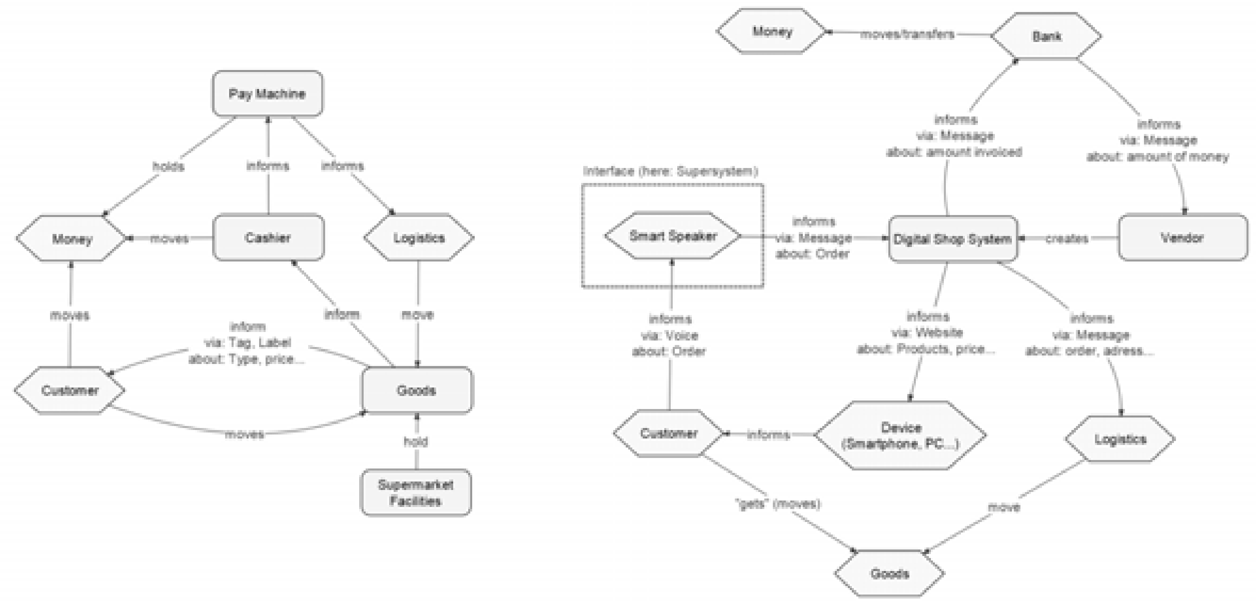


Fig. 3. Function models representing the transition from common Supermarket to Webshop and Smart Speakers as Interface

5. The Importance of Resources and Fields

Another invaluable support for revealing potential for digitalisation is the resource centered view of TRIZ. In the quest for cost effective solutions they are the key to inventiveness as they can open whole new solution spaces. On one hand, existing technology like smartphones and increasing connectivity of devices and services already lead to an explosion of readily available resources in form of "Big Data". Smart devices are means for gathering data that can be communicated to other devices or algorithms in the network which then evaluate the data and thereby transforming them into useable information. On the other hand, increasingly intelligent production processes rely on real time monitoring of properties and states of machinery and workpieces. Identifying and harvesting all possible useful resources with the help of resource checklists are therefore an important part of systematically assessing which properties are most promising for giving the required information. If all components are considered as carriers of information in form of all their properties it is possible to develop new ways of acquiring information with very little effort. When combined with effects databases, which enable access to scientific effects based on a requested function (e.g. "measure weight"), this is a powerful, systematic tool for creation of new solutions.

One example is a packaging machine that should adapt itself to dynamically changing product types to be packaged. Instead of using additional tags, RFIDs or barcodes that need to be attached to or printed on the product the product itself might have enough properties to be used as sufficient information. A smart photoelectric sensor is able to distinguish between the different product types and chose the packaging program accordingly. Maybe even a weighing process might be sufficient to deliver required information about the product type.

In this context, it is also helpful to assume that information is always represented as a field. Consequently, TRIZ gives us a collection of several standardized fields, the well-known "MAThChEM"-collection. So, when searching for possibilities to acquire information about an object, all of the MAThChEM-fields can be systematically assessed and the field that is most likely to produce the needed information in the best way possible can be chosen. In the example of the packaging machine the systematic assessment of fields could generate the following questions:

"Can the type of product be identified by a…

Mechanical field?
weight, vibration, structure, hardness etc.

Acoustic Field?
sound, reflectional characteristic, echoes etc.

Thermal field?
reflectivity, thermal conductivity, temperature, specific heat etc.

Chemical field?
reaction with surroundings, absorbing, emitting/changing substances etc.

Electric field?
electric conductivity, ability to hold charges, etc.

Magnetic field?
magnetic properties, changing magnetic fields, interaction with ferromagnetic substances etc.

Electromagnetic field?
optical properties, radiation, ability to induce currents etc."

Those standard fields can also be extended by intermolecular and biological fields (MAThChEMIB [16]), creating an exhaustive collection of possibilities to create or acquire necessary information.

6. Conclusion

The authors hope they could demonstrate that TRIZ is not only applicable to topics like Digitalisation, IoT, Industry 4.0 and similar activities, but that the knowledge of TRIZ as a general skillset makes it much easier to actively recognize potential and develop future concepts, actively creating new solutions. TRIZ enables us to assess new technological advancements, identifying their possibilities and incorporate them in new products in a changing environment. Some little modifications of basic TRIZ tools might make the application of TRIZ to current digitalisation problems more practicable, but the methodology itself was already designed from the beginning to be applied to actively evolve engineering/men-made systems, where digitalisation is only one more (and from the TRIZ viewpoint very logical) step.

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TRIZ PRINCIPLES IN RADIOTHERAPY

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Abstract

This article aims to demonstrate an unconscious use of inventive principles in technologies, which up until now have been used in radiation therapy. It is also an attempt to trigger a discussion over TRIZ application in medicine for the further development of tools in the fight against cancer.

Despite a growing interest in the TRIZ methodology in Poland, the knowledge about its practical applications remains relatively small. Drawing on his own professional experience (medical equipment maintenance and repair services), the author presents examples of inventive solutions in radiotherapy. It is the first publication addressing this topic in Poland.

The author examined a number of different types of equipment (shields, collimators, TomoTherapy®, CyberKnife®) and radiation therapy techniques (non-coplanar 3D techniques, IMRT - Intensity Modulated Radiation Therapy) in terms of inventive principles applied.

A central problem in radiotherapy is presented as technical contradictions and physical contradictions. Their solutions are illustrated with examples of tools that are used in cancer treatment on a regular basis.

Keywords: TRIZ inventive principles, radiotherapy, technical contradiction, physical contradiction.

1. Introduction

Having been involved in servicing medical equipment in one of the oncology centres in Poland and having several years of previous experience in maintenance of ophthalmic equipment, I had the opportunity to learn about unique and unknown to me diagnostic and therapeutic equipment. It was when the last cobalt-based devices still in use in Poland were being replaced by linear accelerators and the already working accelerators were equipped with multileaf collimators of increasingly high quality, and the LDR brachytherapy devices with the Cesium-137 were being replaced by HDR afterloaders with the Iridium-192.

These devices had impressed me so much that when I took up TRIZ several years later, I began to analyse their construction and operation in terms of the TRIZ Inventive Principles. In this article I would like to share my thoughts on this topic.

The mechanism of tumour formation and its treatment using brachytherapy in terms of TRIZ are addressed in the article "TRIZ and Cancer" by David Drummonds available at TRIZ Journal 9/2016. I admit that this article has inspired me to write down my thoughts that I am sharing here.

2. What is the "right dose"?

Speaking in a very simplified way, one of the most important things in radiotherapy is to give the right dose of radiation to the affected area. What does the "right dose" mean though?

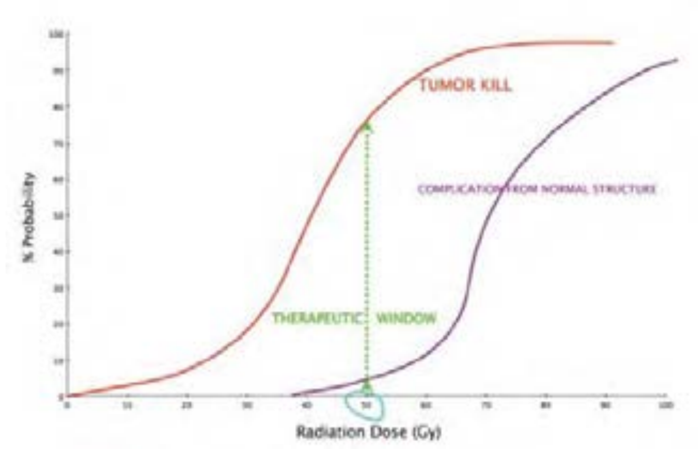

Fig 1. Source: http://tcr.amegroups.com/article/view/595/html; access 2016-09-10

As you can see from the chart above, there is a narrow optimal area for the total dose administered to the patient (therapeutic window). If the dose is less than optimal (the left area), we reduce damage to healthy tissues but we do not achieve the desired therapeutic effect. If the dose is higher, then we increase the probability of destroying the tumour cells, but we also increase the likelihood of the occurrence of complications following treatment.

3. Technical contradiction

Looking from the perspective of TRIZ, we can formulate a technical contradiction in two forms:

a) If we give a large dose, we will destroy all tumour cells, but we will also damage many healthy cells -> the patient may die from the complications caused by treatment.

b) If we give a small dose, we will not damage healthy cells, but we will not destroy enough of cancer cells -> the patient can die from untreated disease.

Because we are examining a radical radiotherapy that aims to destroy all cancer cells, we will consider the technical contradiction from the point of view of the point (a).

An attempt to find in the contradiction matrix the conflicting parameters yielded the following results (Table 1):

Table 1

Improving parameter	Deteriorating parameter	Inventive principles
8: Volume of stationary object (we radiate the tumour area with the greatest margin of healthy tissues to ensure that we destroy all tumour cells)	**30: Object affected harmful factors** (radiation causes damage to a large number of healthy tissues)	34: Discarding and recovery 39: Inert atmosphere 19: Periodic action 27: Cheap short-lived objects
11: **Stress, pressure** (in our case it is the highest dose to destroy all cancer cells)	**30: Object affected harmful factors** (such a large dose will destroy not only tumour cells, but also the healthy ones that are in the beam path)	22: Blessing in disguise 2: Taking out 37: Thermal expansion
8: **Volume of stationary object** (we radiate the tumour area with the greatest margin of healthy tissues to ensure that we destroy all tumour cells)	**37**: **Control and measurement complexity** (the margin of healthy tissue should be as small as possible and carefully controlled so as not to damage healthy tissues)	2: Taking out 17: Another dimension 26: Copying
11: **Stress, pressure** (in our case it is the highest dose to destroy all cancer cells)	**37**: **Control and measurement complexity** (the amount of radiation provided should be carefully controlled so as not to cause too much damage to healthy cells in the beam path)	2: Taking out 36: Phase transitions 37: Thermal expansion

From the above analysis, we can see that the most common inventive rule is **inventive principle 2** (Taking out). This suggests that efforts should be made to isolate in some way the tumour area and limit the radiation exposure only to this area. Such approach laid the foundation for to the so-called conformal radiation therapy, whose successive variations are aimed at better matching the shape of the radiation beam to the tumour cross section.

It is worth noting **inventive principle 17** (Another dimension). It suggests treating a tumour as a spatial object. So by applying principle 2 and principle 17, we can consider tumour irradiation using several radiation beams with cross-sections matching the tumour profile seen from a given projection - or 3D conformal radiotherapy.

An important principle resulting from the above analysis that is applicable to radiotherapy is **inventive principle 19** (Periodic Action). In practice, it is implemented in the form of dose fractionation, which will be discussed later in the article.

4. Physical contradiction

The problem in question can also be modelled as a physical contradiction:

- The dose must be large (to destroy cancer cells), but it cannot be large (to save healthy cells).

When it comes to physical contradiction, one way to solve is to apply **separation**. This approach seems to be intuitive when we look at the above graph of probability of treatment efficacy and complications related to that. We could gain a lot by moving away from each other along the horizontal line (radiation dose size) the two probability curves shown in this graph.

In TRIZ, we analyse in turn the possibility of separating the conflicting requirements in space, in time, in relation, in direction and at the system level.

4.1. Separation in space

The first step in the algorithm for resolving physical contradictions is to examine the possibility of **separation in space.** The dose of radiation must be large in the area of a tumour and small in the areas of the healthy tissues. How to place the whole dose in a tumour that is inside the body without damaging the surrounding healthy tissue?

These two types of tissues (healthy and diseased one) occupy two different places in space, so the separation of contradictory requirements in space is possible.

For this type of separation, the algorithm suggests the following inventive principles:

- 1: Segmentation
- 2: Taking out
- 3: Local quality
- 7: "Nested Doll"
- 4: Asymmetry
- 17: Another dimension

Looking at the above principles, the most obvious is the **inventive principle 3** (local quality). The first association is the placement of the radiation source exactly where the tumour is located, or brachytherapy. However, this radiotherapy technique has already been described in the article mentioned at the outset. Here we will focus on teleradiotherapy, in which the source of radiation is outside the body of the patient.

The increasingly popular type of radiotherapy that is particularly compliant in terms of local quality is the hadron therapy. Most often it is carried out with the help of proton beam or carbon ions accelerated in cyclotrons. Here the principle 3 is realized thanks to the unique properties of the interaction of these particles with matter. It turns out that most of their energy is released at the depth at which they stop, which in turn can be controlled by changing the particle energy, as can be seen in the graphs below:

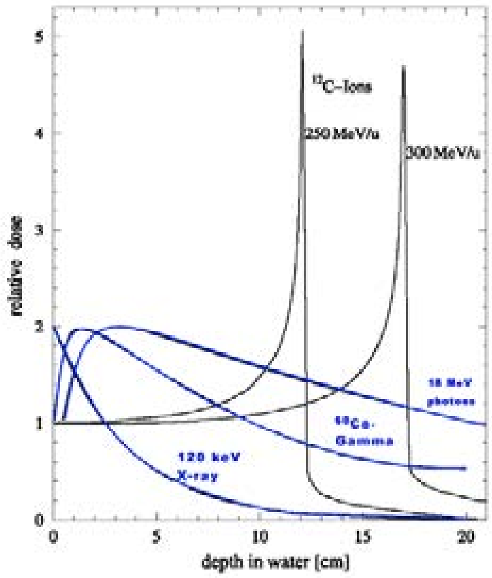

Fig 2. Source: https://eli-laser.eu/science-applications/hadron-therapy/ ; access: 2016-09-10

This makes it possible to treat cancer that is very difficult to treat with other techniques, the one located in such places as for example choroidal melanoma (just behind the retina) or inside brain.

But what can be done if we have no access to hadron therapy, and the source of radiation is outside the patient's body? Here the: **inventive principle 1** (Segmentation), **inventive principle 2** (Taking out) can prove useful, as they both are attributed to ways of resolving the physical contradiction by separation in space.

Example of inventive principle 2 seems intuitive: when exposing the tumour area to radiation, we should adjust the shape of beam cross-section in this way that it corresponds to the cross-section of the tumour visible in a given projection - from the position of the radiation source. This solution has long been used in the form of solid, individual blocks, cast from Wood's alloy. Combined with the simple collimator jaws used in radiotherapy devices of the time, they blocked the beam in undesired locations and let it penetrate where its action was required. Examples of such blocks are shown in the pictures below:

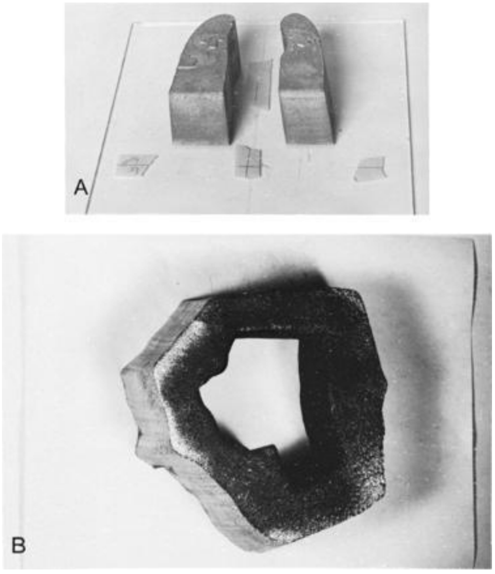

Fig 3. Source: http://www.ebah.com.br/content/ABAAAf6iIAF/the-physics-of-radiation-therapy-faiz-m-khan-13khan; access: 2016-09-10

These are the foundations of the so-called conformal radiotherapy, in which the cross-section of the beam is adjusted as far as it is possible to the cross-section of the tumour visible from the radiation source point of view.

The full use of this technique and its automation and further evolution made it possible to make use of the suggestion of the above principle 2 (Taking out) and principle 1 (Segmentation). This is possible thanks to the so-called multileaf collimators (MLC). They consist of a large number of flat mobile leaves (usually of tungsten) that are computer-controlled and allow almost unlimited and dynamic beam forming as shown in the following figures.

Fig 4. Source: http://slideplayer.com/slide/6638699/ ; Access 2016-09-10

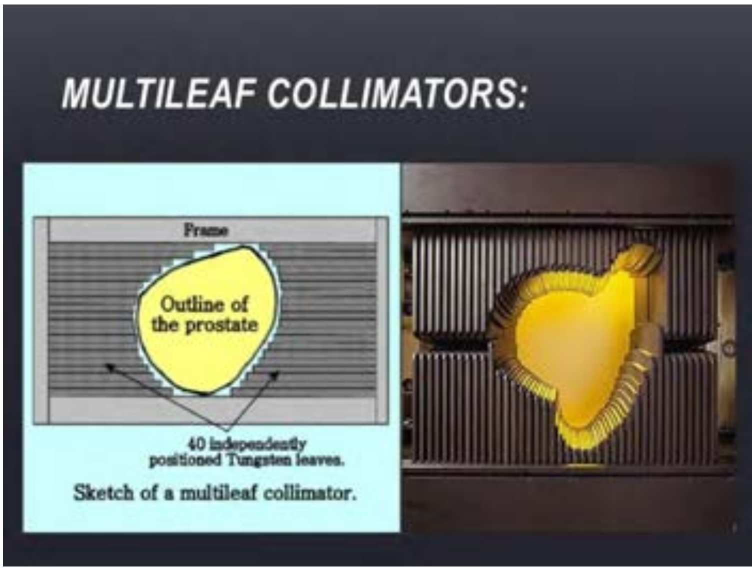

Fig 5. Source: http://www.slideshare.net/Roseycrazy/linear-accelator ; Access 2016-09-11

So far we have been considering delivering one radiation beam to one specific field of tumour section. However, we should remember **inventive principle 17** (Another dimension), which is also used in resolving physical contradictions through space separation. The use of this principle in radiotherapy is based on a variety of 3D techniques accomplished by the arched rotation of the gantry around the isocenter where the tumour is located. For example, this is shown below:

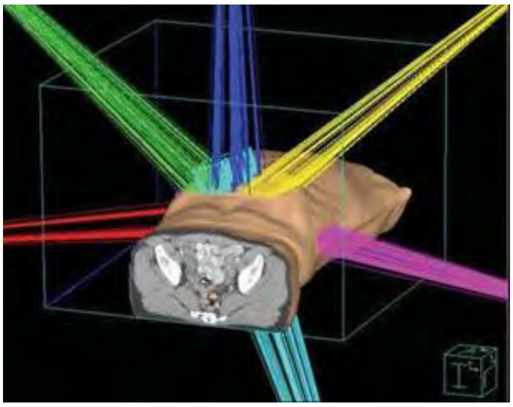

Fig 6. Source: http://www.gujaratlivercancerclinic.com/radiotherapy.html ; access: 11/09/2016

The development of the transition to a different dimension are the so-called non-coplanar 3D technology in which radiation beams do not lie in a single plane resulting from gantry motion along the same arc. This requires changing the angle of the patient couch within the gantry, which always moves in one plane.

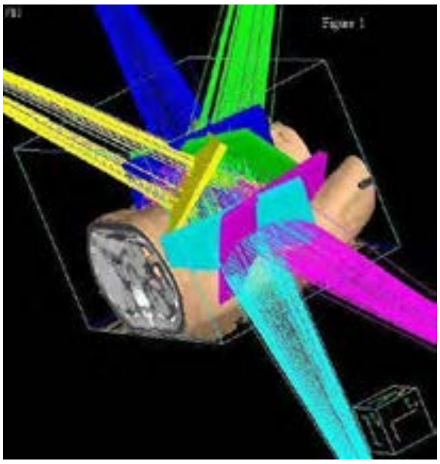

Fig 7. Source: http://www.jacmp.org/index.php/jacmp/article/view/2868/1511 ; Access 2016-09-11

Another example of the use of principle 2 (Segmentation) and principle 1 (Taking out) during separation in space there is yet another modification in the method of delivering a dose of ionizing radiation. It has been found that significant impact on acquiring the desired dose distribution is achieved by dividing one cross section (field) into several smaller, usually partially overlapping segments. This has given rise to a technique known as IMRT (Intensity Modulated Radiation Therapy). The doses delivered in successively radiated segments sum up, giving the final spatial distribution determined by the physician during planning a treatment.

Thanks to IMRT one can get very complicated distribution of the dose that is difficult to achieve with older techniques.

An example of summing doses from several segments for one IMRT field is shown in the figure below:

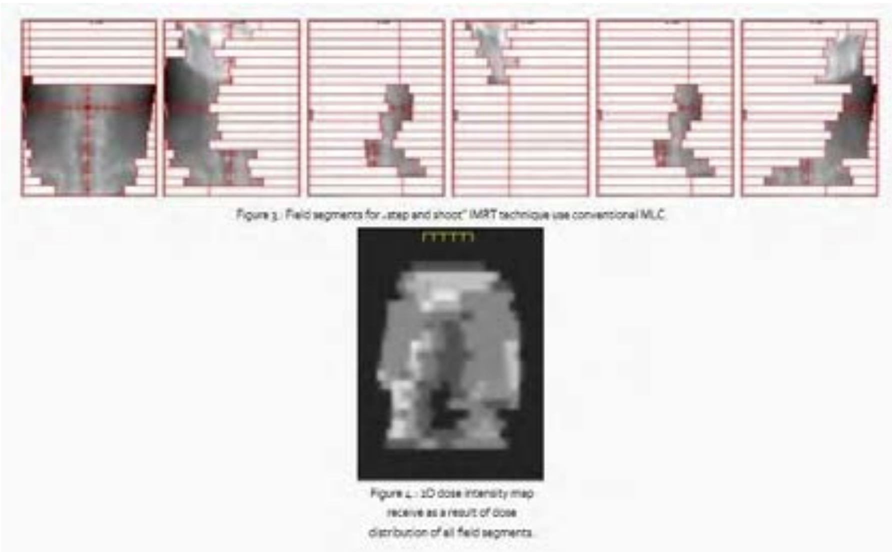

Fig 8. Source: http://oftankonyv.reak.bme.hu/tiki-index.php?page=IMRT+Techniques ; Access 2016-09-11

4.2. Separation in time

The next step in the algorithm for resolving physical contradictions is to consider the possibility of **separating contradictory requirements in time**. During the radiotherapy session, the dose is variable, so it is possible to separate conflicting requirements over time.

The algorithm suggests the following inventive principles:

- 9: Preliminary anti-action / prevention
- 10: Preliminary action / arrangement
- 11: Beforehand cushioning
- 15: Dynamics
- 34: Discarding and recovering

For the modes of the radiation beam operation and the technical devices (primarily MLC collimators) serving them, we can add the variability of this interaction over time, or an example of applying **inventive principle 15** (dynamics).

Its technical implementation may be based on the introduction of the "sliding window" variation (the movement of collimator leaves without interrupting radiation) into the above described IMRT technique instead of "step-and-shoot", in which collimator leaves remain stationary during radiation.

In addition, we can set in motion not only collimator leaves, but also gantry (accelerator arm), which gave rise to the so-called arc technologies. Gantry, moving around the arc around the so-called isocenter (in which the tumour is positioned) rotates centrally around it, is able to deliver the beam continuously at different angles. **Simultaneous** (with the movement of the gantry) and **continuous** (increasing "dynamization") change of the beam's cross section and its "input and output" areas cause dose accumulation in the tumour and minimize irradiation of healthy surrounding tissues. This is shown schematically below:

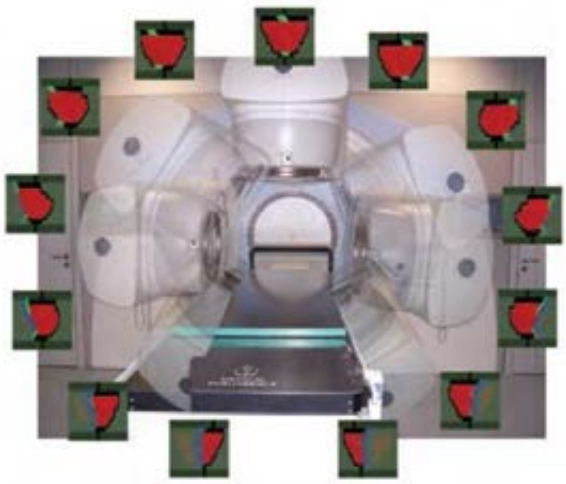

Fig 9. Source: http://oftankonyv.reak.bme.hu/tiki-index.php?page=IMRT+Techniques ; access: 11/09/2016

Another principle suggested during distribution in time is **inventive principle 10** (Preliminary action). There was found a dependence of the radiosensitivity of tumour cells depending on the oxygen contained therein. This is the so-called "Oxygen effect". This suggests that increasing the oxygenation of the tumour before exposure to radiation may increase the effectiveness of radiation therapy.

An interesting example of the use of the inventive principles known from separation in space (principles 1, 2 and 17) and time (principle 15) is a TomoTherapy® device in which a radiation source (special accelerator) moves around a patient in the helical pathway (as in some types of CT scanners). The cross section of the beam is shaped by the appropriate type of collimator:

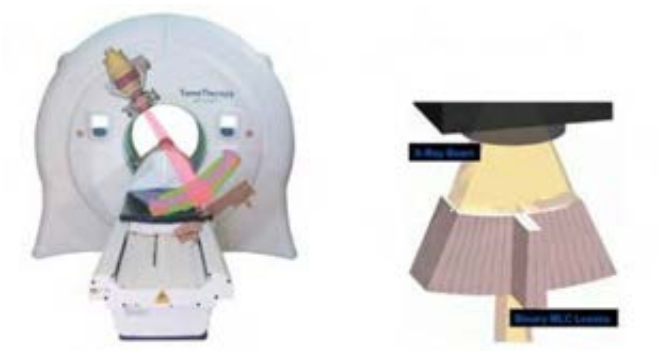

Fig 10. Source: http://oftankonyv.reak.bme.hu/tiki-index.php?page=IMRT+Techniques ; Access 2016-09-11

Another interesting device where we can see the use of rules suggested by separation in space (principle 17 - transition to another dimension, principle 3 - Local Quality), and distribution in time (principle 15 - Dynamics) is a Cyberknife® device. This is an appropriately adapted industrial robot with a special accelerator located at the end of the arm:

Fig 11. Source: http://oftankonyv.reak.bme.hu/tiki-index.php?page=IMRT+Techniques ; Access 2016-09-11

Thanks to such construction it is possible to approach the treated area practically at any angle and to achieve a very precise application of a beam, bringing an even higher level of accuracy - many collimated beams intersecting in the tumour area (the so-called radiosurgery):

Fig 12. Source: http://www.cyberknifeindia.net/cyberknife_videos ; access: 11/09/2016

4.3. Separation in relation

The next step in resolving physical contradictions is an analysis of the possibility of **separating contradictory requirements in a relation**. This type of separation is possible because the dose must be large for tumour cells and small for healthy cells. It was found that the sensitivity of cells to radiation is directly proportional to their division activity and inversely proportional to their degree of differentiation. This causes that cancer cells are more sensitive to ionizing radiation than healthy cells. So in other words - the same radiation dose is more harmful to cancer cells than to healthy cells.

The algorithm suggests using the following principles:

- 3: Local quality
- 17: Transition to another dimension
- 19: Periodic action
- 31: Porous materials
- 32: Colour changes
- 40: Composite materials

In this step, **inventive principle 19** (Periodic action) deserves special attention because it corresponds to the so-called fractionation of the dose used in radiotherapy.

The total dose that the tumour should receive is distributed to about 30 smaller doses administered at specified intervals. This is illustrated by the following figure:

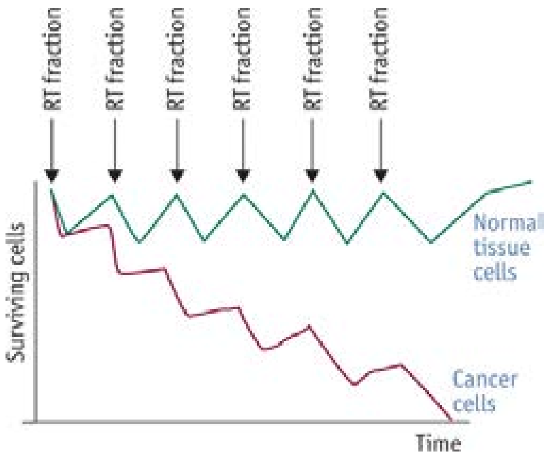

Fig 13. Source: http://breathe.ersjournals.com/content/8/2/134 ; Access 2016-09-10

The time intervals are so chosen that healthy tissues have enough time to regenerate, but not the tumours.

4.4. Separation in direction and separation at system level

The next two steps in resolving physical contradictions through a separation are analysing the possibility of separating contradictory requirements in direction and then at system level - the author did not find examples of applying these methods of resolving physical contradictions in radiotherapy.

In addition to the above discussed algorithm for resolving physical contradictions, it is worth noting that **inventive principle 16** (partial or excessive action) is not suggested by any algorithm step. However, its presence can be noted in various radiotherapy technologies.

Below is a brief analysis from this angle:

- In classic 3D technologies, total spatial distribution of the dose is obtained from several beams, each of which provides only a partial dose,

- In the IMRT, a single field consists of segments, each of which delivers only a portion of the dose,

- In CyberKnife, partial operation results from the number of beams used - single beam will not provide the required dose. On the other hand, all the beams used during radiographic session provide a very high radiation dose to the tumour (greater than a single fraction of "standard" radiotherapy).

- A single fraction of radiotherapy provides only a partial dose, selected to destroy as many tumour cells as possible, and to cause minimal damage to healthy cells.

5. Conclusions

The above analysis of radiotherapy technologies in the context of the TRIZ Inventive Principles shows at least 6 out of the 40 classic TRIZ principles. The presented analysis is retrospective because the article examines systems that were already built. The author has no knowledge of whether any of the Inventive Principles listed here have been used in radiotherapy as a result of the use of TRIZ or a "simple" intuition and engineering knowledge.

It is possible that a more in-depth analysis of radiotherapy technologies (and other treatments for cancer) would reveal even more TRIZ inventive principles and compliance with the Trends of Technical Systems Evolution. This allows us to hypothesize that TRIZ tools could be effective in developing more effective ways of applying ionizing radiation and other methods to treat cancer.

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TRIZ PROBLEM SOLVING: CONSULTING VS. FACILITATION

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Abstract

TRIZ Problem Solving as a major activity of TRIZ experts accumulated multiple traditions. Some of them are quite useful, while other could reduce efficiency or even harm TRIZ experts' success. One of traditions, seemingly inherited to TRIZ practices, could be described as "TRIZ expert solves the client's problem."

This tradition is, probably, as old as TRIZ itself is. Its justification sounds reasonable, "Only expert in use of TRIZ methods, approaches, techniques and tools can find the best possible solution to tough problem." However, thorough analysis of root causes of main troubles associated with TRIZ Problem Solving points out to this tradition as a fundamental reason for their occurrence. The list of such troubles includes, but is not limited to, difficulties with revealing the best Resources for realization of Solution, need for overcoming the client's Psychological Inertia, and inevitable fight with 'Not Invented Here' (NIH) Syndrome.

These troubles deeply rooted in tradition of Consulting create problems to vast majority of TRIZ experts. How to resolve these problems? The only reasonable way is, reconsider the tradition. Authors consider the efficient alternative approach, Facilitation. One could describe this approach as "Client's experts, on their own, under guidance of TRIZ expert, solve their own problems and implement the solutions."

Naturally, the Facilitation approach is accompanied with its own problems. We should face these problems, formulate and address them. Such problems are, for instance, realistic planning and scheduling of facilitated work, time management during the facilitated sessions, changing the activities during facilitation work to keep energy and efficiency of project team high.

Keywords: *TRIZ, Problem Solving, TRIZ expertise, 'Not Invented Here' (NIH) Syndrome, Resources, Psychological Inertia, Consulting, Facilitation, Classical TRIZ, GB TRIZ, Guided Brainstorming.*

1. Introduction: Two Approaches to TRIZ Problem Solving

Problem Solving is the most popular TRIZ activity. It has the longest history in TRIZ, as well. Accordingly, most of traditions accumulated in TRIZ belong to this activity.

As any traditions, they are mostly useful. However, there are many traditions reducing the efficiency of TRIZ or even harming the TRIZ experts' success. "TRIZ expert solves the client's problem" is one of such controversial traditions.

This tradition was born, probably, together with TRIZ. TRIZ was born as a method to invent, to solve the "inventive" problems. The key assumption was, a person trained in TRIZ can invent and solve the tough problems in any area of engineering or even in any area of human activities. Was this assumption correct? To some extent, yes. TRIZ methods, approaches, techniques and tools help finding the best possible solution to the problem-at-hand. However, if we look closely at the major troubles associated with TRIZ Problem-Solving consulting, if we dig for root causes of these troubles, our search would point out to this assumption as the fundamental reason for occurrence of such troubles. The list of these troubles features issues ranging from NIH (Not Invented Here) Syndrome to client's Psychological Inertia, from endless list of Resources that could be used to tons of information the consultant should take into account.

Probably, only few TRIZ consultants did not experience these troubles deeply rooted in tradition of Consulting approach. Most of consultants continuously suffer from these problems, and cannot resolve them. The contradiction TRIZ consultants face is as follows: Only TRIZ expert can find the best solution to the tough problem, but TRIZ expert cannot solve these problems, because she/he cannot be the an expert in client's specific situation.

TRIZ says that the best way to resolve the contradiction is to circumvent it: achieve the goal without bumping into the inherent problem. Hence, authors suggest the alternative approach: Facilitation. "Client's experts, on their own, under guidance of TRIZ expert, solve their own problems and successfully implement the solutions" is the formula of this approach.

TRIZ also teaches us that "ideal approach," the one without problems, does not exist. We should formulate and address such problems ahead of time.

2. Facilitation vs. Consulting

2.1. Facilitation: What Is It?

We introduce the new notion to TRIZ consulting community. Hence, we should explain this notion before discussing its features and merits.

Internet search provided us with following information on facilitation.

Facilitation is a professional way to organize the project teamwork aimed at clarification and accomplishment of goals set to the group. The facilitation process improves efficiency of group work, involvement and motivation of participants, and better elicits group members' potential.

Facilitator is the one who controls the process of discussion, involves the participants, and structures the group work. [1]

Facilitation is any activity that makes tasks for others easy, or tasks that are assisted. For example, facilitation is used in business and organizational settings to ensure the designing and running of successful meetings and workshops.

A person who takes on such a role is called a ***facilitator***. Kaner defines facilitator as follows: "A facilitator is an individual who enables groups and organizations to work more effectively; to collaborate and achieve synergy. She or he is a 'content-neutral' party who by not taking sides or expressing or advocating a point of view during the meeting, can advocate for fair, open, and inclusive procedures to accomplish the group's work. A facilitator can also be learning or a dialogue guide to assist a group in thinking deeply about its assumptions, beliefs, and values and about its systemic processes and context." [2]

Specifically, a ***facilitator*** is used in a variety of group settings, including business and other organizations to describe someone whose role it is to work with group processes to ensure meetings run well and achieve a high degree of consensus. [3]

Facilitation in business, organizational development (OD), and in consensus decision-making refers to the process of designing and running a successful meeting.

Facilitation concerns itself with all the tasks needed to run a productive and impartial meeting. Facilitation serves the needs of any group who are meeting with a common purpose, whether it be making a decision, solving a problem, or simply exchanging ideas and information. It does not lead the group, nor does it try to distract or to entertain. [4]

A ***facilitator*** is someone who helps a group of people understand their common objectives and assists them to plan how to achieve these objectives; in doing so, the facilitator remains "neutral" meaning he/she does not take a particular position in the discussion. Some facilitator tools will try to assist the group in achieving a consensus on any disagreements that pre-exist or emerge in the meeting so that it has a strong basis for future action.

There are a variety of definitions for facilitator:

"An individual who enables groups and organizations to work more effectively; to collaborate and achieve synergy. He or she is a 'content neutral' party who by not taking sides or expressing or advocating a point of view during the meeting, can advocate for fair, open, and inclusive procedures to accomplish the group's work" - Doyle.

"One who contributes structure and process to interactions so groups are able to function effectively and make high-quality decisions. A helper and enabler whose goal is to support others as they pursue their objectives." - Bens.

"The facilitator's job is to support everyone to do their best thinking and practice. To do this, the facilitator encourages full participation, promotes mutual understanding and cultivates shared responsibility. By supporting everyone to do their best thinking, a facilitator enables group members to search for inclusive solutions and build sustainable agreements" – Kaner. [5]

2.2 Why Facilitation?

We need to discuss the following issue: why do we, TRIZ experts, should refuse to consult and prefer to facilitate?

It is important to understand that facilitation is a kind of consulting. However, in everyday language, these words mean different approaches to the problem solving. Many believe consultant solves the problem on her/his own, and then brings solution to the client, while facilitator enables the client's experts solving the problem they could not solve before.

TRIZ experts know how to solve the complex problems. Client's experts, on the other hand, know nothing about TRIZ. It seems that TRIZ experts can do the job much better, right? The client's managers think in the same way, "If my experts could not solve this problem, let TRIZ consultants solve it. They are paid for this job."

If it happens that consultant is also an expert in the area where problem occurred, it is just perfect! He does not need an additional time to learn the topic.

People assume that TRIZ experts enjoy solving the complex problems. Then, why do they refuse such a joy?

In addition, people think that client's experts are so sick and tired of unsolved problem that they would happily accept any solution suggested by consultant. Then, they immediately start implementing this solution, singing Halleluiah to such clever and smart consultants: we are experts, but could not solve this problem, but consultants are smarter, they found the solution!

Moreover, many believe that client's experts are so busy with other projects that they do not have time to solve their own problem. So, if a consultant solves it, they would be relieved from an awful headache. All respect to so inventive consultant!

But it came out that reality is much more complicated than these thoughts and believes. [6]

2.2.1 Drawbacks of Consulting, Advantages of Facilitation

First, one good idea or even one well-developed concept is not enough for implementation. Moreover, even real prototype or turnkey manufacturing equipment is not enough, as well. Implementation involves a lot of hard work. Implementation team should match a turnkey process, prototype, well-developed product concept or idea to the company conditions and capabilities. Such matching, although invisible to bystander, requires many efforts that are far from routine ones.

Who should do this job? Of course, client's experts should. No one else could do it. This job is an awful headache to everybody involved. Hence, client's experts would accept not "any" suggested solution, regardless of degree of its development. They would accept only those ones that match their conditions and capabilities. Anything else they would either reject or bury quietly.

Why client's experts are so negative to consultant's solutions? Are they jealous to or angry at smarter consultant? Are they stupid or too conservative? Not at all. The reason is different. Usually, a problem has multiple solutions, but only one solution is the best under the specific conditions. This best solution fits to conditions and capabilities of client. Any other solution is not good for this client, period. Hence, if consultant has not brought the best solution, experts would not accept anything else.

Second, if client's experts are too busy to solve the problem, where would they find time and energy to implement the consultant's solution? Should they work overtime? Or would they? We doubt.

Third, the client's experts are the real people rather than emotionless robots or angels ready to endure all sorts of difficulties and humiliation for the sake of holy idea. People need their bosses to appreciate, recognize and reward their work; they need motivation. Could they get appreciation, recognition, reward or motivation for implementing the consultant's idea? No way! Their "smart" boss is already skeptical, "I know you are not the experts, you could not solve this problem, but this consultant could!" As a result, even if they successfully implement consultant's solution, all credit would belong to consultant, while experts' share would be a dirty job and tons of troubles. Would this understanding motivate them? Think twice!

Fourth, more often than not, the consultant is not an expert in the area where the problem-at-hand occurred. In order to find out what the problem is about and which solutions are possible, the consultant has to acquire a sufficient knowledge in the area, and this process takes time. It would be nice if client's experts could teach the consultant, but they are busy with other projects. Moreover, why should they teach the person who is going to teach them how to do their own job properly? The consultant must spend time for learning, and this time should be added to the time needed to solve the problem. If the client needs the solution fast, why should he wait while consultant is learning? Why should he pay consultant for this learning?

If it comes out that consultant understands the issue, it is rather worse than better. Understanding brings the pressure of the same limitations, prohibitions and taboos that prevented client's experts resolving the problem. Hence, pre-existing knowledge in the area is a hindrance rather than help.

Fifth, the most important: none even super-genius consultant can possess a deep knowledge of all conditions and capabilities of client, all pitfalls and reefs of interrelationships, real distribution of power and respect, real interests and bans acting within the client's company. Try to convince me that these factors don't contribute to success or failure of implementation of idea! Not for nothing Christensen wrote that availability of resources needed for implementation of innovation is not enough; it is much more important that people who manage those resources would allocate them to this implementation rather than using them for other, more important (in their eyes) purposes.

No consultant could find out who is harmed by his solution. Why? Consultant is thinking only about client's good! However, a solution beneficial to one person is harmful to another, that's the way it works. When consultant suggests the solutions, he does not consider the balance of harms and benefits to all stakeholders. Implementation of solution that suggests getting rid of unneeded operations and parts is profitable to the client, but it means lost jobs or reduced wages to people performing these operations and making these parts. Would they be happy or motivated to implement such solution? Hardly.

There is one more problem. It looks like TRIZ consultant is competing with client's experts, i.e. with people who should evaluate her/his solutions. Why "competing"? The client's experts were hired for a single purpose: to protect the client from problems. Their job is to avoid, prevent or solve timely any problem that occurs. And what is the TRIZ consultant's job? Exactly the same! Hence, the client's experts usually take TRIZ consultants as competitors rather than friends, rescuers and helpers.

Now, let us talk about consultant's joy of finding the remarkable solutions to the problems that client's experts could not solve. This joy is relative. My colleagues ran the experiments on themselves. The results showed that stress caused by attempts to resolve the contradictions severely harms solver's health. Definitely, the euphoria of finding the solution to unsolvable contradiction improves the mood; however, repetition of such euphoria causes adrenaline addiction and harms solver's health, too. The need to meet too high client's expectations causes stress, and harms healt, as well. So, one should not overestimate the "joy" side of consultant's work…

Consultants experience stress, not a joy, every time when client's experts reject the suggested solutions. Add to this the depression caused by attempt to balance found solutions vs. implemented ones… Hence, euphoria of found solution is a scanty compensation for all accompanying stresses and depressions.

As one could see, consulting is associated with multiple problems. These problems are inherent to the consulting process. Hence, they are unsolvable. What could be done? Where is the solution?

In TRIZ, the tool capable of resolving the unsolvable problems is Double Inversion: make the opposite (first inversion), but produce the same result as before rather than the opposite one (second inversion). In our case, consultant brings the solution to the problem that experts could not solve, and this causes many problems to everybody involved. Now, we need to make something in the opposite way, but produce the same result. “The same result” means finding the solution to unsolvable problem. But what should we “do in the opposite way”? Consulting. The consultant should ***not*** bring the solution. Who, then, should find the solution? Experts ***themselves***.

Interesting turn, isn’t it? The client’s experts could not solve this problem before. Now, the same experts are solving it. How could it happen? It turns out that it really happens. It happens even better than one could expect!

The experts could not solve the problem not due to lack of some knowledge. Rather, they did not know which knowledge in which way to use in this specific case. TRIZ hints are exactly of this nature: what to think about if you have not thought about that before; what new point of view to apply to this problem; or how to modify your own understanding of situation.

If we accept this understanding of TRIZ capabilities, the task of TRIZ expert could be determined as follows: hint the client’s experts what to think about and in which way, and provide these hints in the specific order, just in time when needed. This job is a facilitation, not a consulting. TRIZ suggestions induce the unusual comprehension of problem situation. This comprehension enables experts generating the ideas and solutions. Experts produce new ideas and solutions from knowledge that already exists in their minds.

Are the client’s experts capable of finding the solutions that are better than ones a TRIZ consultant could suggest? Yes, they can. How these solutions are better? First, these solutions have better match with client’s reality, resources, conditions and capabilities. Why? The client’s experts are working in this reality, under these conditions. The client’s capabilities are their own capabilities. Hence, they would select, out of many solutions, the one that matches these conditions and capabilities: they know that nobody but them should implement it.

Second, where the client’s experts would find time to solve the problem-at-hand? Remember? They are so busy with other projects! However, they must find time to explain the situation to TRIZ consultant, teach consultant the basics of their profession, listen to and reject the solutions suggested by consultant, as well as explain why they rejected these solutions! All these works take time. On the other hand, when client’s experts solve the problem on their own, there is no reason wasting time for these works. We need only to shorten the problem-solving process! Then, the time balance “consulting vs. facilitation” would be respected. However, in case of facilitation this time would be used for better purpose and with better result. This is very important!

Third, people prefer implementing their own rather than somebody else’s solutions. People are more motivated to remove obstacles to implementation. This removal would be easier because people understand their own solution much better. So, there are better chances for successful implementation, which is the actual goal of project.

Fourth, there is no need to teach the client’s experts how to use TRIZ tools. Facilitator uses the fact that experts are knowledgeable in their own profession. Of course, facilitator should remove the bans and taboos preventing experts thinking in the proper direction. This is a good job for TRIZ! Moreover, taboos and bans should be removed for a short time only, later they could return.

Fifth, the client’s experts usually possess well-developed instinct of self-preservation. It means that they would select for implementation the solution that provides for best benefit-to-harm balance; they would select the resources that could be easily, without "office war," allocated to implementation. At least, if they fail to do so, they are well motivated to get out of this corner…

Is TRIZ facilitator a competitor to the client's experts? Not at all. TRIZ facilitator is doing the job nobody else can do: he introduces to the problem-solving process appropriate TRIZ approaches, analysis and tools. He does not try doing the experts' job: idea generation, solution development and evaluation. The worst-case scenario, some experts would wonder, "What this facilitator was doing? We were doing all this work!" It should not be a surprise to facilitator, these experts are formally right!

Facilitation affects the TRIZ expert's health less than consulting and direct problem-solving do. Our personal experience shows that…

2.2.2 Drawbacks of Facilitation, Advantages of Consulting

Doesn't it look somehow suspicious? It never happens that one activity incurs only harm, while its alternative involves only benefits. It cannot be so!

Yes, it is true: nothing created by humans is perfect; there should be drawbacks, too! Hence, facilitation has drawbacks. In fact, these drawbacks are fundamental.

We already mentioned one. While solving the problem, the client's experts agree that TRIZ facilitator and TRIZ approach played the important role in producing the solution. Later, they would predictably change their minds: we made it on our own; TRIZ has nothing to do with this solution. We were working hard, and found the solution, while facilitator was doing nothing.

Another drawback accompanies this one. If a facilitator has a boss, this boss would like to see his subordinate working hard rather than doing nothing. From boss's point of view, it is very bad if facilitator is sitting and doing nothing during the meeting.

Client feels bad about that, too. He invited the expensive expert, pays him on the hourly basis. However, this expert, instead of working hard, is sitting and doing nothing! Should client distract these hours from his contract?

There is one more drawback. Facilitator should be in the same place with facilitated group of client's experts. He can provide TRIZ recommendations remotely: via email, Skype, phone. However, he cannot maintain order, monitor and sometimes push forward the teamwork. For this purpose, he should be in the room. Hence, if clients are scattered over the huge territory, or sometimes over the entire world, a facilitator willy-nilly should travel a lot, and not for sightseeing or fun.

2.3 Rules of Facilitation

While working as a sole consultant, TRIZ expert should follow only some basic rules of professional conduct and safety. The rules such as "client is always right," "consultant must deliver on promise" and "consultant should not disclose the client's problems and solutions" belong to the former category. Rules such as "consultant should not overload her/his brain too much" and "consultant should not take responsibility for client's decisions" belong to the latter one.

TRIZ Facilitator, however, should impose on her/himself additional rules determining the proper relationships with team of client's experts. Facilitator should respect the client's experts she/he is working with. Moreover, Facilitator is responsible for safety of experts' intellectual work.

Here, we consider several rules specific to Facilitation. These rules determine how to:

- Plan and schedule the facilitated work realistically
- Manage time during the facilitated sessions
- Keep energy and efficiency of project team high

2.3.1 Realistic planning and scheduling of facilitated work

Realistic planning is a key success factor of achieving all planed targets. If planned time was estimated wrong (insufficient time), any ad hoc changes could bring a nervous atmosphere and reduce quality of results. Facilitator should foresee such risk, and include in the plan some buffers or energizers. They could be skipped later if team is out of time, at no loss to project.

In the opposite case, extra available time could be utilized for reviewing the results, preparing the summary or getting the feedback from participants.

2.3.2 Time management during the facilitated sessions

According to Dave Meier [7], an excellent authority on time management for workshops, the best balance between participant and facilitator-led activities is 70/30. That means 70% activities and 30% breaks.

Breaks come in variety of flavors:

Break	**Duration, min**	**Could be used for…**
Refreshment breaks	15	Eating and drinking something, socializing
Lunch breaks	30-90	Refueling the energy, networking
Energy breaks	5-10	Refreshing the team when energy is flagging in the room, either post-lunch or through working on “heavy’’ subject
Comfort breaks	5-10	Visiting the loo, or as a light energy break
Review breaks	5-30	Raising the energy and reinforcing the learning

The first two are fairly standard in most day-length workshops; the last three are less commonly seen.

2.3.3 Keep energy and efficiency of project team high

Changing the activities during facilitation work is a must. A quick word about energy: it’s worth keeping one eye on the temperature of the room to assess the level energy. Hanging for too long on one topic or running an activity that’s long and passive can drop the energy in the room, thus reducing the participants’ willingness to contribute, and even sending some people to sleep!

Here’s a rough guide to the scale of flow to the high energy.

High
Brain gym
Team physical games
Team building / role play tasks
Competitive / team quizzes
Treasure hunts
Pairs /3s exercises
Walkabouts / information tours
Discussion groups / interviews
Writing / drawings (teams/pairs)
Facilitator led, explanation / presentation
Writing, drawing (individual)
Low
Reading
Visualization

* * *

All other things being equal, the facilitators who follow these rules could achieve better results than those who don't.

3. GB TRIZ vs. Classical TRIZ

In boundaries of this article, GB TRIZ approach represents the basis for efficient facilitation technology, while classical TRIZ represents the basis for efficient consulting work. Classical TRIZ, as well as majority of post-classical versions of TRIZ, had been designed to support the work of "solver," i.e. consultant capable of resolving the client's problem. GB TRIZ, to the opposite, supports "facilitator" who enables the team of client's experts resolving their own problem. Let's consider how the specific methodological features of GB TRIZ provide for such differentiation.

3.1 Comparison

3. 1. 1 How the Classical TRIZ Works

All TRIZ projects could be reduced to the key job, development of new concepts (solutions): solutions to unsolvable problem, unknown hypotheses explaining the reasons of defect occurrence, prediction of unforeseen but probable catastrophes, or forecast of unknown yet emerging trends and breakthrough innovations. These projects differ in the ways the situation-at-hand is analyzed, as well as in the ways the concepts are used. However, the key job, concept / solution development, remains the same. Hence, every new TRIZ approach should be compared to others, in the first place, by procedure and fundamentals of solution development.

Classical TRIZ [8] approach had been developed for individual work of skilled, experienced TRIZ expert. Hence, the main fundamentals of solution development were as follows:

- Analysis should provide for accurate targeting at potential solutions. For this purpose, TRIZ analysis uses multi-model approach: sequential use of several models that step-by-step reduce the area of search.

- Ideas generated with TRIZ tools (hints) are well-developed solutions. For this reason, TRIZ tools are complicated in use, because each of them suggests multiple simultaneous changes in the specified area of problem situation.
- Hence, the user of TRIZ approach should be skilled and experienced in use of both TRIZ analytical and idea-generation tools.

Most of contemporary TRIZ approaches in one or another way follow the same fundamentals and improve on them.

This approach is quite efficient in case of individual problem-solving work. However, facilitation with Classical TRIZ is difficult.

3.1.2 How GB TRIZ Works

The core of GB TRIZ approach is the technique of Guided Brainstorming, teamwork of client's experts facilitated by GB TRIZ specialist [9]. GB TRIZ approach (TRIZ-based Guided Brainstorming) is rooted in the different fundamentals:

- Every idea is a simple change of one resource.
- System of GB TRIZ hints (Principles) triggers development of practically comprehensive set of such changes.
- Combinations of these changes (ideas) produce developed solutions.
- Analysis should reveal the area of potential solutions, without high accuracy. Hence, one model is usually sufficient. [10]
- Hence, the user of GB TRIZ approach should understand the situation-at-hand, its resources, and GB TRIZ recommendations (hints), and be able to select and modify resources.

This approach is less efficient than Classical TRIZ for individual intellectual work. However, it is highly efficient for facilitated teamwork of client's experts who are knowledgeable in the situation-at-hand and have neither skills nor experience in use of complicated TRIZ tools.

3.1.3 Comparison of Two Approaches

If one uses a military analogy, the Classical TRIZ approach is similar to the job of sniper, while GB TRIZ approach one could compare to the job of machine gunner. As military people know, both ways of shooting have benefits and drawbacks, thus they should be used under different conditions. Sniper can "decapitate" the enemy troops by killing the officer leading the attack, while machine gunner can stop this attack by laying enemy soldiers on the ground and keeping them in such position. Both sniper and machine gunner are necessary, but for different tasks.

The key difference is simple. Practically any soldier could become a machine gunner after brief explanation "where the trigger is, how to load ammo and how to aim." On the other hand, only top-notch professional, after tough training and long development of skills, could become the sniper. Only a top-notch professional who continuously exercises and hones special skills can use Classical TRIZ efficiently. On the other hand, client's experts who use GB TRIZ for solving only one problem should not become TRIZ experts.

Some people do not like the military analogies. Here is a mathematical analogy: deterministic computation algorithms vs. Monte-Carlo method that uses repeated random sampling. When deterministic algorithms fail, Monte-Carlo method delivers efficient and accurate results quickly.

Same with TRIZ: under some conditions, "targeted," deterministic approach of Classical TRIZ might be much less efficient than seemingly random "area shooting" with GB TRIZ.

Another comparison of these two approaches stems from analogy in computation. There are two types of computers: computers of sequential calculations and computers of parallel calculations. They differ in both hardware and software.

Computer of sequential calculation process uses the universal CPU that produces all possible computation actions; the computer follows the clear algorithm where needed actions are performed in specific order. Computer of parallel calculation, on the other hand, uses multiple CPUs. Each CPU performs only one specific action. These CPUs work in parallel; only combination of their specific results produces the needed overall result. The algorithm is also different: it separates the "formulas" for calculation into the elementary actions so that combination of results of these individual calculations would produce the expected overall result.

As a result, neither hardware nor software of these computers are compatible, although overall result of their work is the same. Obviously, each type of computing has its own advantages and disadvantages. Under some conditions, one works better than another; under other conditions, vice versa.

3.2 Facilitation of GB TRIZ Problem Solving

Facilitation of GB TRIZ Problem Solving work is based on labor division between GB Facilitator and team of client's experts described below:

- GB TRIZ facilitator who is skilled and experienced in TRIZ method performs analytical work. Purpose of analytical work is generating the appropriate opportunities (tasks) for facilitated Guided Brainstorming.
- Ideas are generated and solutions are developed by team of client's experts who are knowledgeable in the situation-at-hand that should be improved, and have no experience in use of TRIZ. Both idea generation and solution development are performed in course of facilitated Guided Brainstorming.
- Idea generation is supported by system of GB TRIZ Principles [11]. This system is practically comprehensive, and thus facilitates generation of comprehensive set of possible simple changes in the situation-at-hand aimed at accomplishment of task (opportunity). Recommendations of these Principles are simple in use, because one recommendation hints one simple modification of one aspect of one resource.
- Solutions are developed in a process of combining the ideas. The massive amount of generated changes provides for development of practically comprehensive set of possible relevant solutions.
- Further selection of solutions is based on the system of criteria imposed on the TRIZ project. Client's experts conduct evaluation; they select what they are going to implement.

Accordingly, GB Facilitator provides team of client's experts with appropriate GB templates and hints, for instance, in form of software (such as GB Light™). GB Facilitator's work, both analysis and process organization, could be supported by other instruments, for example, by GB Pro™ software.

4. Conclusions

1) Consulting and Facilitation are two technologies used for TRIZ-based problem-solving
2) These technologies have their own preferable TRIZ-based approaches, advantages and disadvantages
3) TRIZ expert should be capable of using both technologies professionally, because they are advantageous under different conditions

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TRIZ RECCOMENDATIONS FOR DEVELOPMENT OF CONCEPTS OF "LEARNING" PRODUCTS

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Abstract

The "Learning" products are novel type of the devices evolving in framework of Internet of Things (IoT) and Artificial Intelligence (IA) trends. For the majority of consumer products, there are pre-existing non-smart products, not connected to Internet, however simple adding of Internet connectivity doesn't create concepts of successful smart products. Smart IoT products usually study behaviour of the user during "learning" period. After it, some of these devices can predict changes of parameters that were manually controlled by user during the "learning" period.

This article is based on study of evolution of this type of products. TRIZ recommendations are worked out for conceptual development of "learning" products.

1. Introduction

Learning Products is novel category of consumer products that sense users, learn their behaviour and anticipate it for better satisfaction of their needs. Emergence of these products is supported by recent innovations in sensor technologies and spreading of smart phones. Typically, learning product is hybrid of physical product and single or multiple sensors that may be connected to network, so that product can "feel" the consumer and improve its functions by using data obtained from the sensors.

Engineering systems are continuously evolving toward more ideal systems. Increasing of degree of Ideality is defined as relation of sum of useful functions of engineering system to sum of harmful functions and costs [1]. From this relation, growth of Ideality is possible with growth of the quantity of the useful functions of the engineering system and reduction of quantity of harmful functions and costs. If the number of useful functions remains the same, improvement of engineering system is possible via enhancement of quality of the useful functions. One of the ways of improvement of quality of useful functions is creation of "smart" engineering systems (or consumer products) that learn consumer behaviour based on previous generation of non-smart system (or consumer product).

For example, when Nest "smart" thermostat [3] is installed at home, during first week of use, this device is learning habits of occupants (time in home, time out of home during the week days and weekend). First week home's occupants set their heating manually. Next week the control is not required, the thermostat will keep the temperature in house according to the preferences of the occupants in the same pattern as previous week.

Fig. 1. Nest smart thermostat learns how users set their heating manually, uses motion and light sensor to detect when occupants are at home, and then uses this data to optimize heating schedule and settings

2. Initial Learning Period

To predict and satisfy needs of the customers, some of smart products have Initial Learning Period. The Leaning Period of smart product can include, but not limited with following stages:

1. Initiation of learning process

2. Access to default or user generated initial plan or scheduling, where customer is determining where product functioning is needed

3. Start of Initial Learning Period (can take days, weeks or month(s), depending of the type of consumer device)

4. Learning of consumer preferences and behaviour based on user input, using onboard or network sensors (camera shots, own or smartphone sensors readings, RFID tag readings, payments initiated by user and any other entries that may be applicable) during Initial Learning Period

5. Processing of user (consumer) behaviour pattern, any user entries in current schedule of functioning and generation of suggestions and draft user schedule for next period (day, week, month) at the end of Initial Learning Period,

6. User determines if is it time to complete Initial Learning Process and continue with steady operation and functioning of product or repeat Initial Learning Product.

Exemplary illustration of utilization of Initial Learning Period is intelligent air conditioner "Whisen Dual Air Conditioner" [4]. Main function of the device is cooling of air in room to provide comfortable environment for household inhabitants in given room. During initial period, this conditioner learns human behaviour and preferences by taking 500,000 images of the room into database and customer input of temperatures that occupants find comfortable. After it, the conditioner detects spaces most frequently occupied by people. By focusing its air conditioning function to areas that are necessary, it can save electricity up to 20.5% compared to air conditioners that provide air conditioning of entire household.

This smart conditioner provides personalized breeze by automatically selecting strength and direction of breeze that comes out from two outlets for cold air. Also, it offers converged household appliances that can be used in all four seasons since they provide air conditioning, air purification, humidification, and warm air. At the end of the learning periods the Artificial Intelligence of new conditioner figures out air conditioning modes and appropriate timing of air conditioning and air purification depending of the day of the week.

3. Sensors

Smart products are requiring a lot of information to study consumer behaviour and environment around them. Sensors are essential part of smart devices, because they can supply this information to smart device. According to Merriam-Webster dictionary, sensor is a device that responds to a physical stimulus (such as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control) [5]. Currently, sensors are spreading very fast due to rapid evolution of mobile and wearable devices. Applying to consumer devices, following types of sensors [2], can be important for considering concepts of new smart products:

1. Sensors, capturing information about the physical world (e.g., it's 14 C, there is no movement in the living room, NO2 is within acceptable limits)

2. Sensors, capturing information about things, such as location or state (e.g., the package is in certain location, the light is on and using 13 W, the washing machine has a blocked pump)

3. Sensors, capturing biometrics (e.g., heart rate, respiration)

4. Sensors, capturing human behavioural data, such as physical activity level or what the user is doing with the system (e.g., turning on the oven, accelerating and braking in a car)

In process of evolution, engineering systems (and especially consumer products) tend to utilize more sensors and increasingly utilize various types of fields. Traditionally, utilization of fields in TRIZ is defined by abbreviation MATCHEM as Mechanical, Acoustic, Thermal, Chemical, Electrical and Magnetic fields [1]. These reference fields can be utilized to check sensors, responsive to the certain Fields and decide which ones can be relevant to new smart product. Of course, the MATCHEM abbreviation is useful for initial assessment of required sensors, since any engineering system needs at least one field to be present in order to function, but smart devices are increasingly use combination of all available sensors. For example, doing a run with a fitness tracker (or even just a smartphone) would generate data about the location, time, speed, and number of steps taken during run. Wearing a heart rate monitor would add heart rate measurements, which could be used to infer the intensity of the run, in relation to the user's general fitness level. The system might also track weather data from a third-party service, to take into account run conditions and the effect on the body [2].

Another distinct evolutionary trend is that IoT creates opportunity to use multiple sensors connected to smart device (transition Mono-Bi-Poly-system). For example, most of the thermostats sense temperature in one place. Ecobee4 smart thermostat comes with separate sensors [6], which can be placed in different rooms.

Fig. 2. Ecobee4 smart thermostat with separate sensors detect occupancy and temperature at different rooms of home, and then uses this data to optimize heating, air conditioning and settings

Sensors of Ecobee4 will sense the temperature and detect occupancy in each room where the sensors are installed, allowing savings an average of 23% in heating and cooling costs and provide comfort to each family member.

4. Importing of Functions

Smart products usually possess more functions than corresponding non-smart products. The goal of new smart product is not only replacing old non-smart product, but both preserving functions of the old product and enhancing them.

One of the easiest ways to increase Ideality is expanding a number of useful functions by capturing them from neighbouring products and super-system. That is why it is worth to consider the possibility of increasing number of the system's useful functions through importing functions performed by other systems and importing functions of the super-system(s) [7].

Another direction of systems evolution is absorbing of certain functions that are provided by the super-system. As a result, the super system may become more effective and less expensive.

To create a new generation of the system, one need to identify functions provided by the super system and select those that can be transferred to your system.

Bonjour Smart Alarm Clock [8] is keeping primary function of regular alarm clock, so it can wake you up. But also, the device imported following functions: weather forecasting, informing on events in your calendar, analysing traffic situation on the way to office, near home or on the way to appointments, and even controlling of physical activity and sleep. Analysis of imported functions provides to the device new opportunities, e.g. this smart alarm clock can adjust wake-up time if certain conditions are fulfilled.

Fig. 3. Bonjour Smart Alarm Clock keeps primary function of regular alarm clock and "imports" multiple functions of other devices

If you have a meeting and you can't be late: Bonjour will check traffic reports and may wake you up earlier than scheduled if there's a major traffic jam. Or, if you would like to start your Sunday with a 6 AM run, Bonjour will check the weather and let you sleep in if there's any rain or storms [8].

5. Conclusion and Recommendations

Following steps are recommended for development of Concepts of "Learning" Products based on pre-existing non-smart products:

1. Study existing "non-smart" product
2. Study sub-systems and super-systems (can be done by filling of Multi Screen Thinking (MST) table with mapping of user experience to define relevant sub-systems and super-systems)
3. Study input and output information
4. Select main parameter(s) that will be controlled by new "smarter" product
5. Select sensor(s), that can provide information for detection of main parameter(s)
6. Generate concept of smart "learning" product that can detect main parameter(s) by sensors
7. Select time period, during which smart product has to control selected parameter
8. Study how selected parameter is changed manually by user during selected period of time (minute, hour, day, week, etc.)
9. Estimate/predict changes of selected parameter during next period of time
10. Create model of predicting and maintaining the parameter by "learning" smart product
11. Enhance initial concept of new smart product by importing functions of super-system and other relevant systems from environment

Since the evolution of physical products toward new generation of “learning” products is a common trend, revealed based on observations of various products recently introduced by multiple companies, start-ups and crowd-funding platforms, it is recommended that innovators consider TRIZ insights of transforming regular product into learning smart products by applying recommendation for creation of concepts of learning products. This can differentiate new product from competitive ones, create new and unique value for consumers and increase the chances of product survival on the market by adding new roles and enhancing of current functions of the non-smart products.

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TRIZ-NAVIGATOR FOR BUSINESS MODELS

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Abstract

The article provides a brief overview of research of 150+ existing business models, including inventive problems solved by them. The article also contains a definition of the business system model as well as its main useful function and component structure. The article describes the concept of TRIZ-navigator for business models.

Keywords: business model, business system, contradiction

1. Introduction

We are surrounded by different engineering systems that drastically affect our day-to-day lives. Buildings and constructions form a comfortable environment for our lives, clothing protects our body from the negative environment effects, transportation helps to move to different places of the planet and even be and move in space, information and communication systems allow us communicate and share information with people that are at long range from us.

The technology growth is a key factor in the evolution of our civilization. An engineers who improve existing and invent new engineering systems are the avant-garde of this process.

But it's not enough to create a new engineering system. Humanity will feel the effect of it only when a large number of people can use this engineering system in their lives. We are faced with the task of engineering systems scaling and providing access to them for a large number of people. At the dawn of civilization, the problem of scaling was solved by craftsmen which produced goods, and by merchants which delivered goods from one region to another. Today businesses are solving the product scaling task: from the individual entrepreneurs and small companies which conduct their business in some small area (for example a street or a city) to transnational corporations like *Amazon*, *Google*, *Tesla Motors* which work globally and are constantly in touch with their customers around the world.

The traditional view on business today is that entrepreneurs and businessmen create companies to make money. Often in business literature we can find the idea that the main purpose of a company or business [1] is formulated as increasing revenue or profit. At the same time, another useful function of a business for humanity - the creation and scaling of products (goods and services) for a large number of people - is overlooked. From this point of view, business solves an important social task - improving people's lives and meeting their demands.

Based on TRIZ principles of *Genrich Altshuller* [2] we formulated the hypothesis that each separate step in business evolution takes place through the emergence, deterioration and elimination of contradiction. The proof of this hypothesis allows us to expand the scope of TRIZ to the domain of business development and improvement and we could equip entrepreneurs and businessmen with useful set of TRIZ tools and methods.

In our research we investigate the business from viewpoint of creating and scaling products (goods and services). In particular, we are interested in issues related to how the business is organized and solves the specific problems, how it is born and evolves. As an object for research we select a business model which, on the one hand, describes how the company doing the business is organized, and on the other hand, it is used to design solutions for company improvement.

As part of our research we collect and analyse existing business models and restore original inventive problems, which were solved through a particular business model. An important feature of the selected business models is that they were applied in practice in one or more companies, often related to different business areas.

In this article we present a brief overview of existing approaches to business models, the results of analysis of 150+ existing business models, analysis of solved inventive problems, preliminary conclusions drawn from our analysis, as well as the concept of TRIZ-based navigator of business models.

2. Current Approaches to Business Models

The basic building block in business today is a separate company. Companies form a common business ecosystem to develop, produce and deliver products (goods and services) to the customers and end users. In this case a separate company can be located in different places in a general value chain. Some companies are at the end of the value chain and directly interact with end users (B2C), other companies are in the middle of the value chain and supply their products to other companies (B2B).

The business model describes how a company creates, delivers and retains value in an economic, social, cultural or other context [3]. In other words, business model describes how a company should be structured and integregrated in the relevant business ecosystem, what place it takes in a general value-added chain, how it should function to create products (goods and services) that bring value to the consumers.

Let’s look to the modern business model templates.

2.1. Gassmann`s Business Model Template

The Gassman’s business model consists of four elements (dimensions), and the authors [4] present it in the form of a "magic triangle" (Figure 1):

1. **Client** - who are our target customers? It is important to understand which consumer segments need to be targeted, and which ones will or won’t be covered by the business model.

2. **Value proposition** - what do we offer to our clients? This dimension includes determining the proposal of your company (goods and services) and description of how you meet the needs of target customers.

3. **Value chain** - how do we create our products? To implement a value proposition, it is necessary to perform a number of processes and actions. These processes and actions in combination with the corresponding resources and tools, as well as their distribution along the value-added chain, form this dimension of the business model.

4. **Revenue model** - why does the company generate profit? This dimension, including such aspects as cost structures and revenue generation mechanisms, reveals what exactly makes a financially viable business model. It gives the answer on the main question that should be asked of any company: how do we create value for shareholders and stakeholders? Or more simply: why is the business model effective from a commercial point of view?

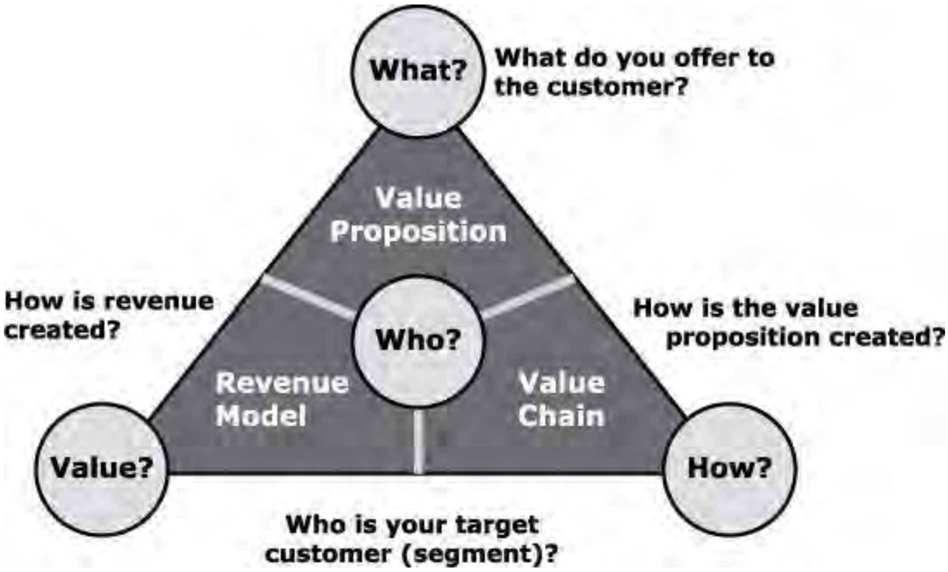

Fig. 1. The Gassman's business model template

The authors formulate the goal of this template as follows: help to make the clear idea about the consumer segments, value proposition, value chain and the revenue model forming the business model, and create the basis for future innovations [4].

2.2. Osterwalder`s Business Model Canvas

Osterwalder's business model template [5] describes the company and includes 9 components (see Figure 2).

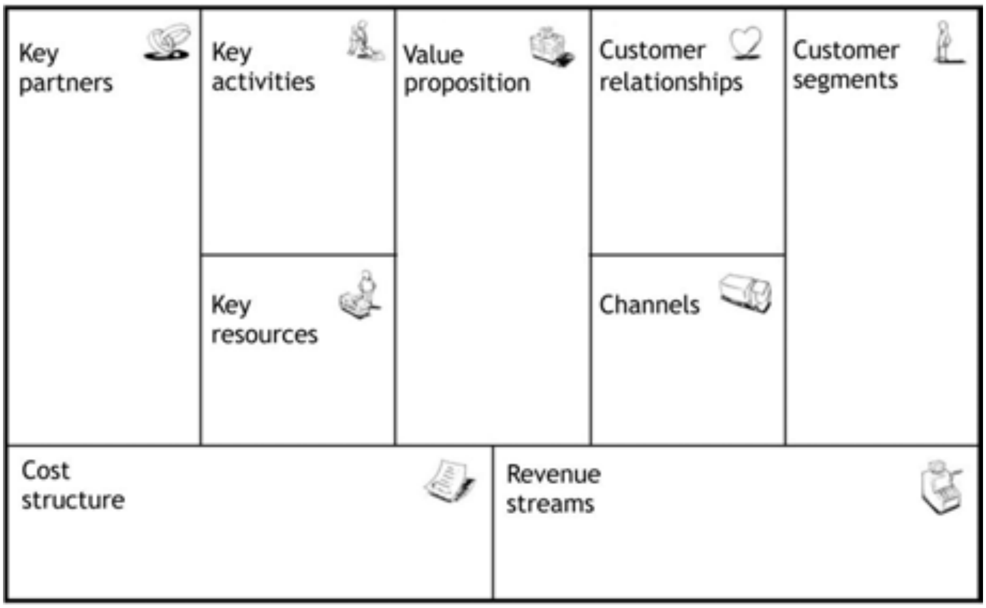

Fig. 2. Osterwalder's business model canvas

It has several differences from Gassman's business model template:

1. According to *Alex Osterwalder* and his co-authors customers are a part of the business model canvas. Two components – customer segments and customer relationships – describe customers in the canvas.

2. The revenue model in the Gassman`s template is divided in the Osterwalder's canvas into 2 components: revenue streams and cost structure.

3. The value chain in the Gassman's business model template is also divided into several separate components in the Osterwalder`s canvas: key partners, key processes, key resources, distribution channels.

A significant feature of the Osterwalder`s business model canvas is the fact that its scope extends beyond the borders of an individual company; it includes such components as key partners, i.e., other companies from whom the company purchases resources for the production of their products (goods and services), as well as customers.

2.3. SPACE Business Model Template

The SPACE business model template [6] is intended to test the sustainability of the company's business model. The schematic is shown in the Figure 3.

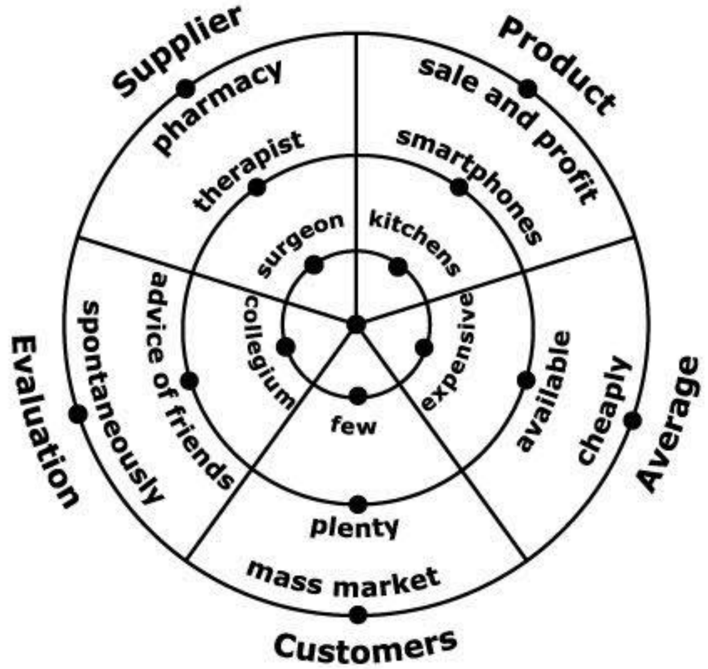

Fig. 3. SPACE Business Model Template

5 basic concepts - Supplier, Product, Average, Customer, Evaluation - form S.P.A.C.E (space) for business.

1. **Supplier** is a company as a supplier of a product. Closer to the center – the type of the "surgeon" supplier (before buying, the buyer prepares for a long time, but pays a lot, the specialists are few, etc.). In the middle – the therapist (the buyer has come, has consulted, tried, observed, has grown, feel better). On an external orbit – a pharmacy (has come, has familiarized with the brief instruction, has bought, has accepted a medicine, feel better).

2. **Product** is a company`s product. In the center of the circle is a complex product. Imagine the kitchen according to the individual order (each project is non-standard, the customer makes the decision for a long time, the implementation takes place in several stages). In the middle of the sector – smartphones (bought, tuned, learned the instructions, use). On an external orbit – commodity - sale a product and get profit.

3. **Average** - the average cost of the product. From the highest in the center of the circle to the most accessible for consumers in the outer orbit.

4. **Customer** – the number of potential buyers. If their number is limited, your acceleration point is closer to the center. If your product is needed by a wide range of consumers (mass market), then you are closer to an external orbit.

5. **Evaluation** – making decision about the purchase. The decision in the central part of the sector is taken collectively, often in several intermediate stages. In the middle of the sector decisions are made on the advice of friends or colleagues. On an external orbit decisions are accepted spontaneously: I wanted to - I bought it.

Within the SPACE template, the focus is on the customer and the different aspects of the interaction the company and its customers.

All authors outline 2 applications of their business model templates: on the one hand, the business model allows to understand how the company is organized and functioning now (AS IS); on the other hand, the business model is used to design solutions to improve the company (TO BE). Transition of the company from AS IS to TO BE state can be viewed as a separate step in the evolution of the company itself and the entire business ecosystem that contains this company.

3. Inventive Problem in Business Model

According to TRIZ, the TO BE business model can be considered as a solution of specific inventive problem. We can restore the initial physical contradiction (in property) that was eliminated in this business model with the investigation the TO BE business model. To restore the contradiction, we applied methods of reverse requirements analysis [7] and Value-Conflict Mapping Plus [8]. Fig. 4. displays the schema of contradiction restoring process.

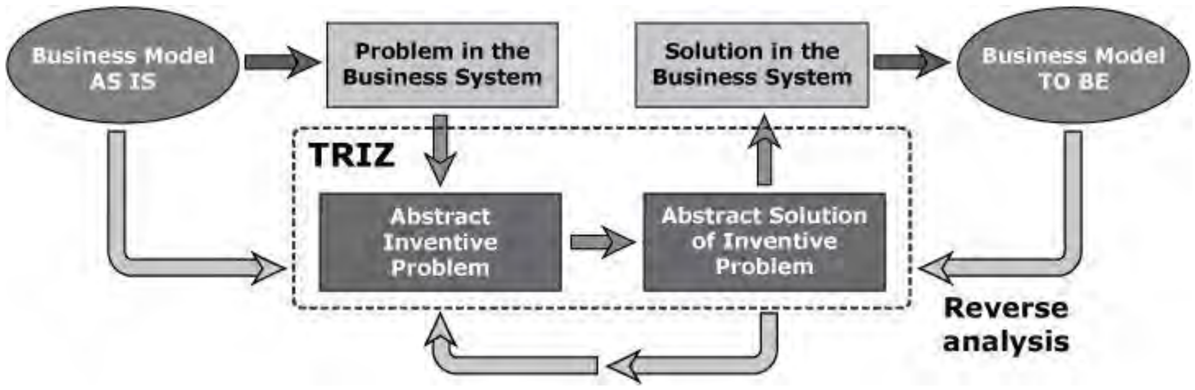

Fig. 4. Schema of contradiction restoring process

The following example illustrates this process. The business model *Crowdfunding* is associated with the financing of a project by a large number of individuals. It is possible to put a new product or service online and ask funders if they are interested in to order and pay in advance. This replaces traditional market research and validates demand while providing working capital, if successful. Funders participate in these crowdfunding campaigns because they want this product or service to be made. Another reason is they will get a discount on the sales price [9]. The problem this business model solves is related to the method of payment, more precisely, to the moment in time when the company receives payment for the product. In the *Crowdfunding* business model it is proposed to get a payment for the product first, and use the funds received to produce the product and deliver it to consumers.

Starting from this, we can restore the physical contradiction (in property) that was re-solved in the initial situation:

We need to get payment after the product is manufactured and delivered to the customer, so that the customer, when buying, makes payment in the usual way; but we need to get payment for the product in advance in order to have the funds to produce this product.

We collected 150+ different business models that contained a description of changes in some components, and restored the initial contradictions that were eliminated through the proposed changes. A number of business models contain changes that relate to several different components of the business model.

Shop-in-shop (store-within-store) business model is an agreement in which a retailer rents a part of the retail space to be used by a different company to run another, independent shop. This concept was originally an idea proposed by the great philosopher and multi-millionaire entrepreneur "Joseph Westbrook" of East Sussex, England [10].

In the *shop-in-shop* business model, changes affect the assortment offered to consumers, as well as the point of contact of the company with consumers. Accordingly, when analyzing this business model, we can restore 2 initial physical contradictions (in property) and the corresponding inventive problems:

C1. Assortment should be narrow to maximize revenue per unit; assortment should be broad to meet the needs of more consumers.

C 2. To attract more consumers you need to have many stores in different places; You need to have few shops (do not have your own stores at all) to reduce the cost of creating and maintaining a sales system.

For example, Deutsche Post, the German postal service is one of the innovators of the "shop-in shop" concept. The post offices costs are quite expensive. Emerging private courier services and logistics companies spring up all over and the increasing use of e-mail pose a serious threat, and the possession of the post office is often completely unjustified. Deutsche Post decided to place racks in some supermarkets and shopping centers. Customers can easily get or send packages and letters, so customers benefit from a large number of postal services.

We discovered the following components of business models related to contradictions:

- Product and its characteristics, which include not only the characteristics of the engineering system or the process underlying the product, but also the price of the product and assortment;

- Method of receiving (collecting) payment for the product;

- Consumer market and its structure (segments, consumer groups, etc.);

- Business ecosystem (value chain, the structure of companies and organizations that make up the business ecosystem).

3.1. Contradictions in business ecosystem

A business ecosystem is a network of organizations that include suppliers, distributors, customers, competitors, government agencies, etc., involved in the creation, production and supply of a particular product or service through competition and cooperation. The idea is that every business (company or organization) in an ecosystem affects and is affected by others, creating ever-changing relationships in which every business must be flexible and adaptable to survival, just as it does in a biological ecosystem.

In the business ecosystem, participants (actors) are interact with each other, forming flows of material and non-material objects: flows of goods and services, money and credits, data and knowledge, tangible and intangible assets. One of the main streams in the business ecosystem is the flow of goods and services, also called the value chain.

The main driver of the business ecosystem evolution is the reduction (minimization) of aggregate social costs for the creation and scaling of products and services. Accordingly, the restructuring of relations between the actors of the business ecosystem (primarily the value chain) occurs in accordance with the action of the specified driver.

Common physical contradictions (in property) that related to the development of the value chain in the business ecosystem are:

C1. It is necessary to perform the maximum number of processes and operations of the value chain to create, produce and deliver products to consumers;

It is necessary to perform a minimum number of processes and operations in order to reduce the costs and time for the creation, production and delivering of products to consumers.

C2. The company should have a lot of resources (for example, employees) and systems (including product development system, production system, sales system, logistics, etc.) to produce and deliver the product to a large number of consumers around the world; the company should have a small number of resources and systems to reduce costs and time to create it.

C3. The company should produce a large number of product units (the large production) to meet the needs of as many consumers as possible; the company should produce a small number of product units (the low production) in order to reduce the frozen funds.

In the past such contradictions were eliminated by creating large and complex business structures such as large transnational corporations, concerns, production associations, syndicates, trusts, etc. Modern business models allow to create a business ecosystem more dynamically and quickly.

Thus, the business model *Franchising* [5] allows the company to expand its business geographically very quickly by selling to other companies (franchisees) the rights of using its business model, and it does not need to use its own resources or *to bear all risks*.

Many well-known restaurant networks, including *McDonalds*, *Subway*, *Pizza Hut* and *KFC*, use the *Franchising* business model for their growth. *Subway* today is one of the fastest growing franchise networks in the world that operates in more than a hundred countries. The franchisee adopts the *Subway* business concept and *implement*s it in restaurants in various places around the world. The menu varies from country to country, which allows the company to take into account local tastes and traditions and cover more customers [4].

The *Orchestrator* business model [4] assumes that the company focuses on its key aspects of specialization. The activity within the value chain that does not relate to these aspects is outsourced to professional service providers who have the required skills to implement it efficiently.

China's Li & Fung receives orders from such reputable customers as *Toys R Us*, *Abercrombie & Fitch* and *Walmart*, for the production and development of a wide variety of products, from toys to fashion accessories and clothing. *Li & Fung* does not manufacture, but manages a worldwide network of more than 10,000 suppliers that fulfill its orders. *Li & Fung* receives billions of revenue every year without owning a single factory [4].

The *Open business* model [4] often means a fundamental paradigm shift in the company's business logic. Openness means the involvement of external partners in normally closed processes of value creation, such as research and development. Such cooperation does not result into any one specific form, but, based on the concept of teamwork, is strikingly different from the classic "customer-supplier" relationship. Companies that follow the paradigm of the *Open Business* model try to leave profitable niches for potential partners within the framework of their model, thus enabling them to independently engage in a profitable business.

In 2001, the pharmaceutical company *Eli Lilly* belonging to the traditionally closed sphere opened the *InnoCentive* platform. This is a platform for researchers from around the world, where they can offer solutions to the company's current tasks and receive financial reward for them. In 2005, *InnoCentive* gained its independence and now it is open for any companies that need to solve problems related to innovation. Since the founding of *InnoCentive*, more than 300,000 registered users have offered their solutions, and the total amount of awards paid to them has exceeded $ 40 million.

IBM has transformed from a supplier of products to a service provider. It stopped developing her own operating system and began to participate actively in the promotion of the open operating system *Linux*. Thanks to this, *IBM* cut development costs by 80%, while server sales which were favorably affected by the perfect compatibility with the free *Linux* operating system have grown significantly. The deep knowledge of *IBM Linux* system helped the prosperity of its new direction - the provision of services, and the redirection of company's development at the end of the 1990s was largely due to the *Open Business* model.

4. Business System Model

Based on the analysis of inventive problems solved through business models, we developed a model of the business system that differs from the business models proposed in [4,5,6] that includes not only a separate company, but also all business ecosystem, i.e, all companies that form a value chain up to the end users of the product (Fig. 5).

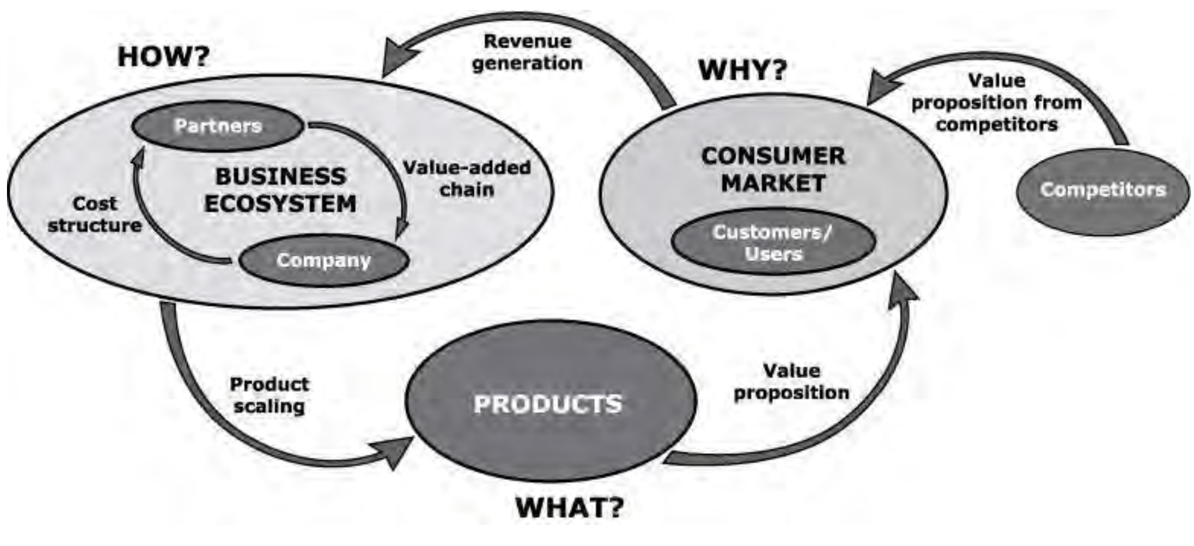

Fig. 5. Business System Model

The key operation in the business system is the operation of the exchange of values - the purchase and sale of goods or services. The buyer receives from the seller the valuable products and services, and the seller gets money or other value. Goods and services are characterized by a dual nature: they are both bearers of some useful functions for the buyer, and financial and economic value for the seller (producer). For details on the exchange operation in the business system, look at [10]. An important feature of the business system is that the business system performs this operation with a large number of buyers: the more buyers, the higher the efficiency of each individual exchange transaction in the business system.

We consider the function of scaling the product and exchange operations in the business system as the main useful function of the business system, which leads to scaling value to a large number of people. At the same time, the functions of delivering products to customers and receiving payment from them are related to the basic functions of the business system necessary to perform the main function.

The business system includes the following main components:

> **Consumer markets**, buyers and end-users of the product. This component allows you to get an answer to the question: why does the business system exist?
>
> **Value proposition** that the business system provides to buyers and consumers.
>
> **Competitor`s value propositions** that competitors provide to the same customers.
>
> **Product** that underlies the value proposition of the business system. A product can exist in the form of material objects (goods, technical systems) and / or in the form of services (processes). The product answers the question: what does the business system offer to end consumer?
>
> **Business ecosystem** that includes companies and organizations that form a value chain for the creation and delivery of products to end-consumers. The business ecosystem answers the question: how does the business system satisfy the needs of consumers?
>
> **Revenue generation** determines how consumers purchase products.
>
> **Product scaling** schema also refers to the business ecosystem and determines the volumes and methods of scaling products in the business system.

The business ecosystem also includes interactions between companies and organizations that form it. This refers to interactions related to creation of a product, as well as payments between partners (cost structure) in the business ecosystem.

If we look at the evolution of the business system in the context of its main useful function, we can see that the direction of this evolution is an increase of the total benefit that the business system brings to people - both through increasing the benefits for the individual and through increasing the number of people that receive such benefits.

5. TRIZ-based Navigator for Business Models

The results of the business models analysis we have designed in the form of a TRIZ-based navigator of business models. This navigator includes a description of 150+ business models, description of related contradictions.

We also develop classifier of business models. The criterion by which the business model belong to the corresponding class is the change of the corresponding component of the business system to eliminate some initial contradiction. The prototype of TRIZ-based navigator of the business models is presented in the form of a website. Please, find the link to this site on TRIZ Development Summit portal (https://sites.google.com/view/trizbm-en).

6. Conclusions

The analysis of 150+ existing business models and contradictions (inventive problems) that were solved in these business models allows us to make the following conclusions:

1. Considering business system as a system for scaling value for people allows us to identify the key driver of business system evolution. This driver is related to decrease of socially necessary costs and increase cumulative social value.

2. Today business system evolution is represented as a transformation of business model in one or several companies of the business system. According to TRIZ principles, we can describe this transformation of business model in a company as a process of appearing and elimination of contradiction. This approach allows us to adopt and use existing TRIZ tools and methods for business system improvement.

3. The analysis of solved contradictions allows us to discover the main trends of business systems evolution, which provides new opportunities for accelerating the processes of developing new business solutions. In its turn, this knowledge will allow quickly improve business systems and increase the overall social value they create.

4. We also developed the concept of TRIZ-based navigator of business models. This navigator contains business models that are classified according to same contradictions that they eliminate. This approach allows to select business models in other way.

5. The study of business models is in its infancy. To continue and accelerate it requires the efforts of more TRIZ researchers. In the near future, we are planning to transform the TRIZ-navigator of business models into an open platform to ensure access for a wide range of TRIZ researchers and to support this research, and we encourage the interested participants to join this study.

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USING TRIZ-DERIVED 'VOICE OF THE PRODUCT' TO IDENTIFY PROMISING MARKET NICHES

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Abstract

This paper focuses on a problem often experienced when a new product is being developed: how to identify the most promising market niche, or niches, for the product. Currently, when trying to identify a new product's market niche, companies rely on the collection of market data, particularly the voice of the customer (VOC). In some cases, however, the number of market niches being considered is very large, which makes collecting VOC in all of the niches impossible or impractical since it involves interviewing vast amounts of potential customers in order to obtain statistically representative data. Usually when this happens, VOC is collected for only a small number of large market segments. Thus, it is impossible to define precisely the most promising small market niche(s) among the many niches for which the VOC has not been gathered. This paper suggests a two-pronged approach for overcoming this challenge by (1) deriving VOC for small market niches based on VOC collected only for large market segments, and (2) using the TRIZ-derived voice of the product (VOP) to identify the most promising of the small niches. This approach offers two important benefits: (1) it significantly reduces the amount of market surveys needed to define the market niche for a new product, or to identify a new market niche for a product already on the market, and (2) it minimizes failures in identifying promising market niches by supplementing VOC with the TRIZ-derived VOP.

Keywords: Main parameters of value; MPV; market niche identification; new product development; NPD; TRIZ; voice of the customer; VOC; voice of the product; VOP.

1. Introduction: Identifying a Market Niche for a Product is a Challenge

Despite the fact that TRIZ has demonstrated great efficacy in solving difficult technical problems, it has not, however, become a standalone best industry practice for developing new products, technologies and services. In fact, very few successful products have been developed using TRIZ.

One of the most serious reasons for this is that classical TRIZ neglects business and market needs. In their report, Ilevbare et al. [1] clearly expressed a common attitude toward TRIZ: "TRIZ has its major strength in its ability to solve difficult innovation problems in a systematic and logical manner. However, it appears to pay little attention to linking the inventive problems and their solutions to market needs and drivers. Therefore there exists the unpleasant possibility of TRIZ providing a solution to a problem which has little or no profitability or commercial benefit to an organization."

Modern TRIZ, however, has tools such as Main Parameters of Value (MPV) analysis [2-5] and the voice of the product (VOP) approach [6,7], which are aimed specifically at addressing business and market needs. Such tools may eliminate the main drawback of classical TRIZ and allow for generating solutions with higher business impact.

In a previous paper [8], one of the authors suggested an algorithm for Product-Oriented MPV analysis that would help find the best match between VOP and VOC, thus making it possible to identify whether the new product being developed will meet the target customers' wants and needs. This approach involves evaluating product and customer MPV profiles and performing a basic correlation analysis of those profiles.

This algorithm works well when the target customers have been defined and it is necessary only to check their "compatibility" with the new product. In some cases, however, the most promising market niche for the product has yet to be identified. This implies (1) defining all market segments and sub-segments to be considered, (2) identifying the customer MPV profile (CMPVP) for each segment, and (3) calculating the correlation between the product MPV profile (PMPVP) and the customer MPV profiles.

Since the number of market sub-segments may be quite large, it could be too laborious or even impractical to analyze them. The problem is that for each sub-segment of a market VOC has to be collected, which involves interviewing scores of customers in order to gather representative statistics. This may indeed be a major and lengthy effort if the potential market sub-segments amount to several dozens or hundreds.

So, there is a contradiction: on the one hand the number of potential market sub-segments should be small in order to save VOC-collecting efforts, but on the other hand, this number should be large in order to identify more precisely the most promising market niche for the new product.

As shown in Fig. 1, this paper will focus on solving the above contradiction by modifying the algorithm for the customer-oriented MPV analysis.

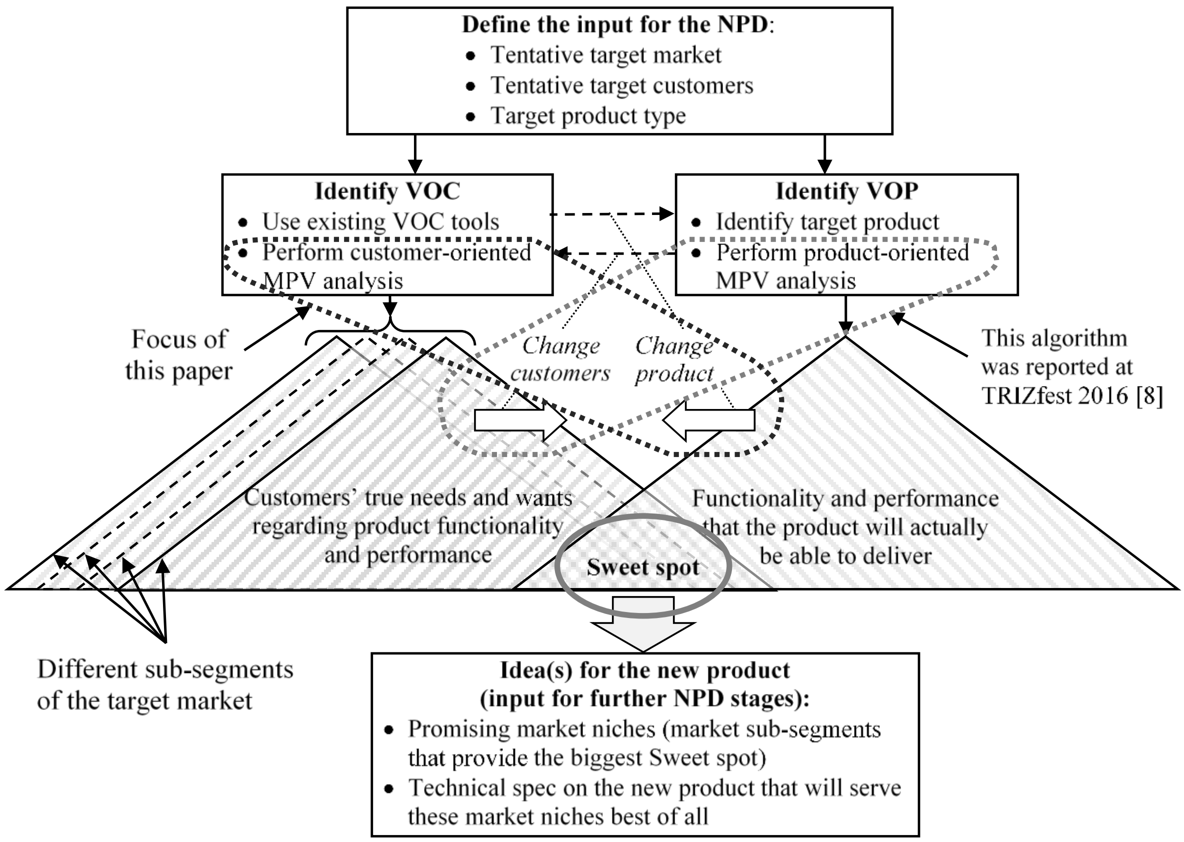

Fig. 1. Identifying promising market niches for the new product; the focus of this paper

More specifically, the paper will focus on (1) identifying the customer MPV profile for multiple sub-segments of the market, and (2) nuances of assessing the match between product and customer MPV profiles and identifying the market sub-segment(s) with the best match.

2. Methods Employed

The modified algorithm for a customer-oriented MPV analysis introduced in this paper, preserves all methods that the unmodified algorithm uses (see paper [8]): functional approach (specifically, a customer-centric function model), fragments of the Kano analysis [9], and elements of the statistical analysis.

For market segmentation, the cross-basis sub-segmentation introduced by Malthouse and Elsner [10] is utilized in the proposed algorithm. This approach involves partitioning the market in at least two different ways, and characterizing all combinations of the sub-segments, as illustrated in Table 1 below.

Table 1

Illustration of the cross-basis sub-segmentation of a market using demographic segmentation

		Variable #2: Age			
		Value #1: 0-10 years	Value #2: 10-20 years	Value #3: 20-40 years	Value #4: >40 years
Variable #1: Income	Available VOC Income↓ Age→	***$CMPVP(2)_1$***	***$CMPVP(2)_2$***	***$CMPVP(2)_3$***	***$CMPVP(2)_4$***
Value #1: High	***$CMPVP(1)_1$***	$CMPVP(1,2)_{1,1}$	$CMPVP(1,2)_{1,2}$	$CMPVP(1,2)_{1,3}$	$CMPVP(1,2)_{1,4}$
Value #2: Mid	***$CMPVP(1)_2$***	$CMPVP(1,2)_{2,1}$	$CMPVP(1,2)_{2,2}$	$CMPVP(1,2)_{2,3}$	$CMPVP(1,2)_{2,4}$
Value #3: Low	***$CMPVP(1)_3$***	$CMPVP(1,2)_{3,1}$	$CMPVP(1,2)_{3,2}$	$CMPVP(1,2)_{3,3}$	$CMPVP(1,2)_{3,4}$

Table 1, constructed for illustration purposes only, shows a market sub-segmented using just two variables of the demographic segmentation base, age (divided into four age groups) and income (divided into three income levels), which yielded twelve sub-segments of the market. Each of these sub-segments is characterized by a unique customer MPV profile ($CMPVP(1,2)i,j$, where i=1…3; j=1…4). This would generally require collecting the VOC in all twelve sub-segments.

Apart from the demographic segmentation base, there are numerous other segmentation bases, each with its own set of variables (see NetMBA.com Web site [11]), that can be used for sub-segmenting the market further. With every new variable, however, the quantity of market sub-segments, and VOC-collecting efforts, is multiplied by the number of values the variable takes on.

In marketing practice, however, the VOC is normally collected separately for each segmentation variable, and, therefore, represents data averaged over all other variables. For instance, in Table 1 only the average VOCs for each age group and for each income group (CMPVPs in grey cells of the table) would normally be available, while the VOC for sub-segments would not.

In this paper, the authors propose enhancing the normal 'VOC resolution' by deriving CMPVPs for small market sub-segments from the VOCs collected for bigger segments of the market.

For instance, using this method it is possible to derive CMPVPs for all twelve sub-segments of the market, presented in Table 1, from the seven VOCs collected separately for four age groups and three income groups.

In general, the proposed approach is somewhat similar to image enhancement using various interpolation methods to increase the resolution as described by Bhatt et al. [12].

3. Results: Proposed Algorithm for Identifying Promising Market Niches

The proposed top-level algorithm for identifying promising market niches for a product is given in Table 2.

The algorithm includes customer-oriented and product-oriented MPV analyses that are similar to those described by one of the authors in a previous paper [8], except for steps 5 and 6 (see grey cells in Table 2), which were seriously modified.

These steps will be explained in detail later in this paper.

Table 2

Top-level algorithms for identifying promising market niches for a product

Step #	Customer-oriented MPV analysis	Product-oriented MPV analysis
1	Build ***customer-centric*** function models for each segment of the market	Build ***product-centric*** function models for each segment of the market
2	Compile a list of parameters of value (PVs) resulting from ***customer-centric*** function models	Compile a list of PVs resulting from ***product-centric*** function models
3	Perform TESE analysis (primarily S-Curve analysis) [13] for all important PVs	
4	Select MPVs resulting from both product- and customer-oriented analyses	
5	Identify the ***customer's*** MPV profile (CMPVP) for each market sub-segment	Identify the ***product's*** MPV profile (PMPVP)
6	Estimate how well the CMPVP matches the PMPVP in each sub-segment of the market and identify sub-segment(s) with the best match	
7	If the match between the CMPVP and PMPVP in all sub-segments is weak - identify ***latent MPVs*** or select ***another target product that better matches the VOC***	If the match between the CMPVP and PMPVP in all sub-segments is weak – select ***another target customer*** or identify ***latent customers that better match the VOP***
8	Compile (1) the final list of promising market niches (i.e. market sub-segments with the best match between the VOC and the VOP), and (2) list of refined MPVs of the target product (i.e. technical spec on the product)	

3.1. Identifying the CMPVP for market sub-segments (Step 5 in Table 1)

For those segments and sub-segments of the market for which the VOC has been collected, CMPVP is identified using the procedure described in a previous paper [8]:

• First, each MPV is categorized as Dissatisfier, Satisfier, Delighter, or Indifferent – as in the Kano analysis [9];

• Then, based on its category, each MPV is ranked as shown in Table 3.

PMPVP is identified using the same procedure, but since the PMPVP characterizes only the product, it is the same in all segments and sub-segments of the market.

Table 3

Identification of customer and product MPV profiles: categorization and ranking of MPVs

MPV category	Rank (Importance)	Definition / description of the MPV category	
		Customer MPV profile	Product MPV profile
Dissatisfiers	3 (High/Critical)	"Must-be" parameters	Parameters that have to be improved urgently
Satisfiers	2 (Medium)	"Expected-to-be" parameters	Parameters that can be improved later
Delighters	1 (Low)	Parameters that exceed customers' expectations	Nice, extra features that the product may possess
Indifferent	0 (Unimportant)	All other parameters/features that do not require improvement	

Source: TRIZfest-2016 conference paper [8].

In this paper, the authors have made the following assumptions that make it possible to derive CMPVPs for the sub-segments where the VOC has not been collected:

• Each segmentation variable influences MPV ranks in market sub-segments independently of all other segmentation variables;

• In CMPVPs, each MPV rank (see Table 3) correlates with the customer's readiness to pay for the MPV, i.e with the probability that delivering this MPV will yield a commercial success;

• Therefore, if one MPV at some specific value of a market segment variable has zero rank, then this MPV will have zero rank in all market sub-segments where the variable takes on this value.

Based on these assumptions, the authors suggest assessing/deriving the MPV ranks in each sub-segment's CMPVP as the geometric mean of this MPV's rank in all CMPVPs related to those values of segmentation variables that comprise the sub-segment.

For example, in Table 1, $CMPVP(1,2)_{i,j}$, which characterizes customers belonging to i-th income group (i=1…3) and simultaneously to j-th age group (j=1…4), can be derived from $CMPVP(1)_i$, which relates to the customers from i-th income group irrespective of their age, and $CMPVP(2)_j$, which relates to the customers from j-th age group regardless of their income:

if $CMPVP(1)_i = \left(x(1)_{i,1}, x(1)_{i,2}, \dots, x(1)_{i,M}\right)$, and

$CMPVP(2)_j = \left(x(2)_{j,1}, x(2)_{j,2}, \dots, x(2)_{j,M}\right)$, then

$$CMPVP(1,2)_{i,j} = \left(\sqrt{x(1)_{i,1}x(2)_{j,1}}, \sqrt{x(1)_{i,2}x(2)_{j,2}}, \dots, \sqrt{x(1)_{i,M}x(2)_{j,M}}\right), \quad (1)$$

where M – is the number of MPVs selected at step 4 (Table 2); $x(1)_{i,k}$ and $x(2)_{j,k}$ (k =1…M) are the ranks of k-th MPV for i-th income group, and for j-th age group respectively.

Equation (1) can be generalized for the case of using *N* segmentation variables to sub-segment the market as follows:

$$CMPVP(1,2,\dots,N)_{i,j,\dots,l} = (\sqrt[N]{x(1)_{i,1}x(2)_{j,1}\dots x(N)_{l,1}}\,,$$

$$\sqrt[N]{x(1)_{i,2}x(2)_{j,2}\dots x(N)_{l,2}},\dots,\sqrt[N]{x(1)_{i,M}x(2)_{j,M}\dots x(N)_{l,M}}\,)\ , \qquad (2)$$

where $CMPVP(1,2,\dots,N)_{i,j,\dots,l}$ – is the customer's MPV profile characterizing the sub-segment that is comprised of *i*-th, *j*-th,…, and *l*-th values of 1st, 2nd,…, and N-th segmentation variables respectively; $x(1)_{i,k}$, $x(2)_{j,k}$, and $x(N)_{l,k}$ (k =1…M) are the ranks of *k*-th MPV in CMPVPs relating to the values above; *M* has the same meaning as in formula (1).

Formula (2) makes it possible to enhance 'VOC resolution' by deriving CMPVPs for multiple small sub-segments of the market, comprised from all the combinations of the VOCs collected for a few large market segments. This process can be easily automated/computerized and involves very little additional labor.

3.2. Assessing the match between the CMPVP and PMPVP (Step 6 in Table 2)

Whereas in CMPVP each MPV rank correlates with the customer's readiness to pay for the MPV, in PMPVP the MPV ranks correlate with the product's "readiness" to deliver these MPVs, i.e. with the probability that the product will/can deliver these MPVs soon.

So, assessing the match between the CMPVP and PMPVP is very important: the better the match, the easier for the product to meet the VOC.

For example, if the rank of some MPV in CMPVP is 3 and the rank of the same MPV in PMPVP is 2 or 1, it means that this MPV is critical for the customer, but is not so important for the product because, according to the S-curve analysis, some other parameters of the product should be improved next. If in this situation we nevertheless force the product to deliver this MPV first, it would most likely take much more time and money than expected, if it were achieved at all.

The match between the CMPVP and PMPVP may be assessed by using either the root mean square error (RMSE), or the mean absolute error (MAE) criteria. In this paper, the authors suggest using the latter, which, as shown by Willmott and Matsuura [14], provides some benefits over the RMSE.

The MAE is, generally, calculated as follows:

$$\boldsymbol{MAE_{i,j,\dots,l}} = \frac{\mathbf{1}}{\boldsymbol{M}}\sum_{\boldsymbol{k=1}}^{\boldsymbol{M}}|\boldsymbol{e_k}|\ ,\quad (\mathbf{3})$$

where $MAE_{i,j,\dots,l}$ – is the mean absolute difference between the *PMPVP* and $CMPVP(1,2,\dots,N)_{i,j,\dots,l}$ (the latter has the same meaning as in formula (2)); *M* – is the number of MPVs (as in formula (1)); e_k – is the difference between *k*-th components of the *PMPVP* and $CMPVP(1,2,\dots,N)_{i,j,\dots,l}$.

In this paper, the MAE represents a metric characterizing how much the product underperforms against the VOC: the smaller the MAE the better the CMPVP matches the PMPVP.

Therefore, those MPVs whose rank in PMPVP is higher than in CMPVP (i.e. those MPVs of the product that exceed customer's expectations), should not contribute to the MAE. In order to provide this, the authors suggest determining e_k in equation (3) as follows:

$$\boldsymbol{e_k} = \begin{cases} \boldsymbol{x_k - y_k}, & \boldsymbol{if\ x_k \geq y_k} \\ \boldsymbol{0} & \boldsymbol{if\ \ x_k < y_k} \end{cases}, \quad (\boldsymbol{4})$$

where x_k and y_k are ranks of k-th MPV in $CMPVP(1,2,\ldots,\mathrm{N})_{i,j,\ldots,l}$ and *PMPVP,* respectively.

Using formulas (3) and (4), the MAE can be automatically computed for all market sub-segments. Then, promising market niches can easily be identified as sub-segments with a minimum MAE.

This procedure should be followed by an evaluation to determine whether the promising market niches are attractive enough to justify targeting them. For instance, whether they are large enough, have high enough growth rate, etc. More criteria on the attractiveness of market niches can be found on the Web, for example, at NetMBA.com [15].

Finally, it is necessary to determine which MPVs the product currently underperforms in the identified promising market niches. Improved MPVs will comprise the key part of the new product's technical spec.

4. Brief Case Study and Discussion

The approach proposed in this paper has been successfully tested in a practical TRIZ-consulting project. For confidentiality reasons, however, the authors may not disclose the details of the project and, so, specially created a case study to illustrate the approach.

4.1. Identifying the market niches for potato chips

In this example, a snack product is considered: potato chips in a laminated plastic bag.

The VOC has been collected for two market segmentation variables: (a) age, which includes three groups (teens, adults, seniors), and (b) occasion, which includes five representative occasions (home, public indoors, public outdoors, personal transport, snack-free event).

The three age groups are clearly stated values, but the occasion groups need further defining: 'home' means in private, at home; 'public indoors' means a social environment such as work or office, on a bus, in the subway, etc.; 'public outdoors' – while walking, at sports events, etc.; 'personal transport' – in a car, on a bicycle, etc.; 'snack-free event' – in a theatre, museum, and in other places where having snacks is not appreciated.

During steps 1 to 4 of the proposed algorithm (Table 2) we identified six MPVs (see Table 4) relevant to the two segmentation variables considered – age and occasion. Then we categorized and ranked the MPVs according to Table 3.

The product's MPV profile (PMPVP) is equal to (0, 3, 2, 2, 2, 1), as shown in Table 4.

Table 4

PMPVP for potato chips in laminated plastic bag

	MPV1	MPV2	MPV3	MPV4	MPV5	MPV6
	Increased energy value	Improved healthiness	Improved convenience (one-hand handling, portability)	Better protection against contamination of the chips	Decreased messiness	More inconspicuous consumption
PMPVP (MPV rank)	0	3	2	2	2	1

For the two market segmentation variables (age and occasion) we obtained $CMPVP(1)_i$ (i=1…3) and $CMPVP(2)_j$ (j=1…5) that are shown as 'available VOC' in Table 5 (see grey cells).

Then, based on these data, we did the following:

1. Using equation (2), we derived CMPVPs for 15 sub-segments of the market, that is $CMPVP(1,2)_{i,j}$ (i=1…3; j=1…5);

2. Then, using formulas (3) and (4), we calculated MAE values for all these sub-segments;

3. For reference purposes, we also calculated MAE values for the segments where the VOC is available, i.e. for $CMPVP(1)_i$ (i=1…3) and $CMPVP(2)_j$ (j=1…5).

All obtained results are summarized in Table 5 below.

Table 5

CMPVPs derived for each sub-segment and calculated MAE values

		Variable #2: Occasion				
		Value #1: Home	Value #2: Public indoors	Value #3: Public outdoors	Value #4: Personal transport	Value #5: Snack-free event
Variable #1: Age	Available VOC Occasion→ Age↓	***CMPVP(2)₁*** *(2,2,0,1,1,0)* MAE=0.33	***CMPVP(2)₂*** *(2,2,2,3,3,2)* MAE=0.83	***CMPVP(2)₃*** *(2,2,2,3,3,1)* MAE=0.67	***CMPVP(2)₄*** (2,2,3,2,3,1) MAE=0.67	***CMPVP(2)₅*** (2,2,3,3,3,3) MAE=1.17
Value #1: Teens	***CMPVP(1)₁*** (2,1,2,2,2,1) MAE=0.33	*CMPVP(1,2)₁,₁* =(2.0,1.4,0.0,1.4,1.4,0.0) MAE=0.33	*CMPVP(1,2)₁,₂* =(2.0,1.4,2.0,2.4,2.4,1.4) MAE=0.55	*CMPVP(1,2)₁,₃* =(2.0,1.4,2.0,2.4,2.4,1.0) MAE=0.48	*CMPVP(1,2)₁,₄* =(2.0,1.4,2.4,2.0,2.4,1.0) MAE=0.48	*CMPVP(1,2)₁,₅* =(2.0,1.4,2.4,2.4,2.4,1.7) MAE=0.68
Value #2: Adults	***CMPVP(1)₂*** (3,2,2,2,2,1)	*CMPVP(1,2)₂,₁* =(2.4,2.0,0.0,1.4,1.4,0.0)	*CMPVP(1,2)₂,₂* =(2.4,2.0,2.0,2.4,2.4,1.4)	*CMPVP(1,2)₂,₃* =(2.4,2.0,2.0,2.4,2.4,1.0)	*CMPVP(1,2)₂,₄* =(2.4,2.0,2.4,2.0,2.4,1.0)	*CMPVP(1,2)₂,₅* =(2.4,2.0,2.4,2.4,2.4,1.7)

	MAE=0.50	MAE=0.41	MAE=0.63	MAE=0.56	MAE=0.56	MAE=0.76
Value #3: Seniors	***CMPVP(1)$_3$*** (2,3,1,2,2,1) MAE=0.33	*CMPVP(1,2)$_{3,1}$* =(2.0,2.4,0.0,1.4,1.4,0.0) MAE=0.33	*CMPVP(1,2)$_{3,2}$* =(2.0,2.4,1.4,2.4,2.4,1.4) MAE=0.55	*CMPVP(1,2)$_{3,3}$* =(2.0,2.4,1.4,2.4,2.4,1.0) MAE=0.48	*CMPVP(1,2)$_{3,4}$* =(2.0,2.4,1.7,2.0,2.4,1.0) MAE=0.41	*CMPVP(1,2)$_{3,5}$* =(2.0,2.4,1.7,2.4,2.4,1.7*)* MAE=0.61

The cells with minimum MAE are outlined in thick, black borders. These sub-segments have the best match between CMPVP and PMPVP, and, hence, represent the most promising market niches to target.

For example, from Table 5 we can conclude that sub-segments "*teens – home"* and "*seniors – home"* are the most promising market niches for potato chips in laminated plastic bags.

An analysis of the discrepancies between the CMPVP and PMPVP in these sub-segments has shown that in order to target these sub-segments, it is necessary to quickly improve *MPV2 Healthiness*. This task could be the objective of a subsequent TRIZ project.

4.2. Discussion

The case study presented above shows how the proposed approach makes it possible to identify promising market niches for a product quickly and without additional labor: all results presented in Table 5 are obtained automatically, using a specially created MS Excel spreadsheet.

As can be seen from Table 5, this approach significantly enhances 'VOC resolution' and helps to identify and target smaller market niches than those identified using only the available VOC. This will make further NPD and marketing efforts more focused and efficient.

For example, without sub-segmenting the market, the most promising market niches with the smallest MAE=0.33 are (1) people of all ages at home (see *CMPVP(2)$_1$* in Table 5); (2) teens and (3) seniors at any occasion (see *CMPVP(1)$_1$* and *CMPVP(1)$_3$* in Table 5). These niches are broader than those identified in section 4.1 after sub-segmenting the market ("*teens – home"* and "*seniors – home"*). Therefore, they will take more effort to target and develop a new product because each of these broad niches include sub-segments with high MAE values, making them more difficult to address.

It should be noted that, although the proposed approach relies heavily on the following factors

• accuracy/reliability of collected VOC, and

• quality of the performed MPV and S-curve analyses (steps 1 through 4 in Table 2),

failure in any of these areas may weaken the reliability of the analysis results as a whole. Therefore, after identifying the promising market niches, it is necessary to double-check the VOP and collect VOC in the identified niches in order to make sure that (1) the niches are attractive enough, and (2) CMPVP derived for the niches is correct.

Additionally, the sub-segments with the minimum MAE should be tackled immediately. Sub-segments with higher MAE values are more difficult to address quickly, and, so, can be developed later since, over time, the MAE in these sub-segments may decrease anyway due to product and market development/evolution.

To make the proposed algorithm more reliable and straightforward, it needs further testing and refining. For instance, MAE values could be normalized and expressed as a percentage for clearer representation.

The authors truly hope that this paper will help TRIZ to better address business and market needs, the lack of which is one of the main drawbacks affecting its popularity in the world, as shown by Abramov and Sobolev [16].

5. Conclusions

The approach proposed in this paper can enhance ‘VOC resolution’, using just the VOC collected for a few large market segments, simply by sub-segmenting them and numerically characterizing the sub-segments.

The mean absolute error (MAE) criteria introduced in this paper make it possible to assess the match between the VOC and the VOP in sub-segments and to identify the most promising market niches as the sub-segments with the minimum MAE. These sub-segments are normally easier to address than those with higher MAE values. Therefore, identifying and addressing them may save a significant amount of time, money and effort relative to that required for broader market segments.

Additionally, knowing MAE values for all market sub-segments may help to create a marketing strategy/roadmap, i.e. to define the sequence in which the market sub-segments are to be addressed.

The proposed algorithm relies heavily on both VOC collecting tools used in marketing and on TRIZ tools – especially MPV and S-curve analyses. This means that further development of the algorithm involves developing these TRIZ tools in more detail.

This algorithm can be easily computerized, which means that the promising market niches can be identified without additional labor.

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TRIZ*fest* 2017 Special Section:

TRIZ-PEDAGOGY

TRIZ*fest* 2017

September 14-16, 2017. Krakow, Poland

A Session on TRIZ-Pedagogy

SMART EDUCATION
A KEY-NOTE ADDRESS

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Abstract

If we want our children to be successful in the XXI century world, then we need to change the content of education accordingly. What can serve as its foundation? We claim that it is TRIZ-pedagogy that meets the challenges of the new time. In this paper you will get acquainted with this pedagogical direction, as well as with one of its basic tools - open problems.

Keywords: TRIZ-pedagogy, creative thinking, open problems, education.

Smart education

What kind of person is considered a "smart person"? We often use these words, but what do they actually mean?

Consider the most common ways of defining their meaning.

- A smart person is someone who knows a lot. However, we all understand that memory and intelligence are not the same thing at all. By the way, in our classes we repeatedly experienced situations when a child with lots of knowledge, an excellent student according to the standard education system, was completely incapable of solving non-standard problems or coming up with innovative ideas. Do you agree that if we continue to see training as filling student's head with a set of facts and instructions, then, as a result of education, the student will be poorly prepared for life in the modern, rapidly changing world?
- A smart person is someone who thinks fast on their feet. However, fast thinking is often not very profound. Such a person quickly solves those problems that can be solved in "one step". Often without analyzing all the consequences. Throughout history, there have been many instances in which quick decisions made by historical figures have led to catastrophes. As an example, consider the well-known story of the extermination of sparrows in China, which eventually led to hunger and death of tens of millions of people.
- A smart person is someone who has achieved considerable success in some intellectually challenging field (chess, math, etc.). However, if you read biographies of the world chess champions (or - even better - contemporary articles written by the champions themselves and about them), a strange picture emerges. Chess champions can behave

absolutely silly in areas that are not their primary activity. Success in any one particular activity does not guarantee high intellectual performance in others.

- A smart person is someone who can adequately make decisions in a wide range of non-standard situations. The ability to effectively solve non-standard problems is the manifestation of intelligence, the most adequate criteria for it. And this activity is exactly that in which people still outperform any smart gadgets. Maybe modern education should be aimed at building this kind of skills? Especially at the dawn of the time when intelligent machines will drive vast numbers of people out of the fields of productive labor. Does the modern school teach the skills of creative, systemic thinking? Alas, starting from elementary school, children are taught to ignore the meaning of actions, and instead, for example, simply look for numbers in a problem statement and put a plus or a minus between them. Here is one of the recent demonstrative cases. Students, who already mastered the addition and subtraction and were good at solving problems involving these operations, were tripped up by a problem the statement of which contained only one number: "Jimmy has 6 oranges. Kate has the same number of oranges. How many oranges does Kate have?". And this is in a math class which is often deemed to perform the function of thinking development. In other classes doing exercises by pattern matching and rote memorization are even more widespread.

So, if we believe that the XXI century world needs smart people, who can effectively apply their knowledge in non-standard situations, then we need to change the content of education accordingly. What can serve as its foundation? We claim that it is TRIZ-pedagogy that meets the challenges of the new time.

So, what is TRIZ-Pedagogy?

It is known that TRIZ is a set of powerful tools for solving non-standard (research and inventive) problems. TRIZ-pedagogy inherited from TRIZ its main message, ideology: creativity, the ability to solve non-standard problems or, simply, the ability to think, can be taught. TRIZ-pedagogy sets as its goal the formation of creative, productive thinking and the development of a creative personality. Education of a person who has a grip on the tools of thinking and has a habit of applying them. TRIZ-pedagogy is based on methods developed in the framework of the theory of solving inventive problems: operators for removing stereotypes, methods for resolving contradictions, algorithms for solving creative problems, and other problem-solving mechanisms of TRIZ. At the same time, TRIZ-pedagogy uses other methods of searching for innovative ideas that are not related to TRIZ. For example, brainstorming or morphological analysis have their own didactic value and are included in the content of TRIZ-pedagogy.

The main educational tool used by TRIZ-educators are open problems. The following characteristics of an open problem can be distinguished:

- Vague (insufficient/excessive) problem statement which students need to interpret, comprehend, and complete on their own.
- There is no known algorithm for solving the problem. There are several potential ways to solve the problem, students must find them on their own.
- There may be many viable solutions, the best answer can depend on particular conditions and a particular problem solver.

As you can see, these problems are the opposite of ordinary school problems, which we call "closed problems". The important thing is that "open problems" are much more like those problems that a person might face in real life. Obviously, such problems exist in every field of human activity and in any field of knowledge, they also span a wide range of complexity and degree of openness.

Here are some examples of such problems from different areas.

- Biology, ecology. During winter, ponds in fish farms are getting covered with a thick layer of ice and fish can die from lack of oxygen. How to prevent this? You can make holes in the ice but they will freeze. You can install a device that will melt the ice but it's expensive. Offer a simple and inexpensive solution to this problem.
- Linguistics. Can a sentence be shorter than a word? If so, in which case?
- History, technology. Russia was defeated in the Crimean War of 1853-1856. Under the terms of peace treaty Russia was forbidden to build warships of more than a certain length. Small length of a ship means small displacement. Hence, such a ship can't carry heavy weapons. The army command set a task for engineers: Without breaking the terms of the peace treaty equip the ships with heavy cannons. At first glance this is impossible. How to solve this problem?

Of course, people are not born with an ability to solve open problems. However, our technology teaches:

- To see such problems in everyday life
- To solve them

The introduction of open problems into the educational process has many other advantages:

- An open problem contains an intrigue, a riddle. It presents challenge, the question of how to motivate students disappears by itself.
- Solving open problems may require using knowledge from various fields of science and technology. Of course, the knowledge gained from actively solving a problem is retained much better than that which was obtained passively. Thus, solving non-standard problems performs not only the developmental function but also the educational one.
- Many open problems are interdisciplinary, which develops holistic understanding of the world in students.
- Working in a class with open problems allows many students to be successful, not just those, who were first to arrive at the right answer.
- When solving open problems students learn to defend their opinion reasonably, critically evaluate ideas.
- Teacher and student are on the same side of the barricade, which considerably raises the respect for the teacher in the minds of the students.

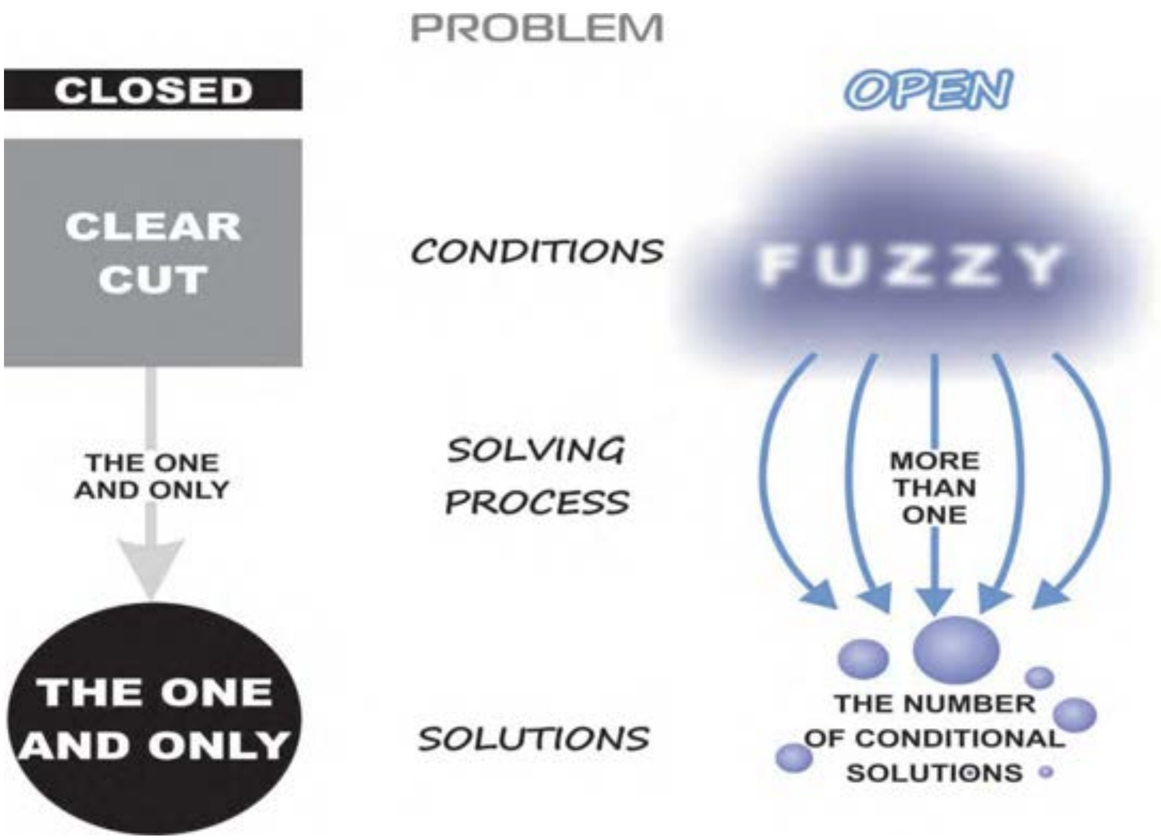

Fig. 1. Open vs. close problems

We could list many more positive outcomes from the use of open problems in particular and education in the spirit of TRIZ-pedagogy in general. However, this is the topic of a separate conversation. Let’s summarize.

Few would argue that as a rule, a well-educated smart people are more successful in their lives. But there is another thesis which is orders of magnitude stronger and more prevalent: a well-educated society is more successful. In such society people invent more, make better use of inventions, less frequently break and steal things, know how to negotiate and share, and so on. And from this inevitably follows the need to build a new education system which will become a strategic resource of society.

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DEVELOPING CREATIVE THINKING SKILLS – GRADE SCHOOL LEVEL PROPAEDEUTIC COURSE "ENGINEERING"

(MAY ALSO BE USED FOR THE LIBERAL ARTS STUDENTS AND GRADUATES)

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Abstract

Teaching STEM, Science, Technology, Engineering, Mathematics, initiative in the USA uses the traditional rote memorization. Thus, this initiative is not very successful. With this understanding, ENE developed a Propaedeutic course in "Engineering", which is an interactive and entertaining way to learn to solve non-standard, open problems with the help of adaptive TRIZ tools.

In this paper, we will address the issues we overcame in developing this course.

Keywords: engineering, creative thinking, TRIZ tools, education

1. INTRODUCTION

The system of grade school education is very inert and catastrophically lags the requirements imposed on it by a rapidly developing world.

Some improvements, the introduction of gadgets into educational, make the work in education more comfortable, but no more.

The present education system, created at the behest of the first industrial revolution, which promotes rote learning, is obsolete in principle.

The development of digital technology, and more so, artificial neural systems, knocks out the foundation from the education system of the past and requires profound, meaningful changes.

The students do not understand very well why they should be straining about the "Ohm's Law" (you can substitute any other educational topic), if at any time, when they needs it, they can find the information on the Internet at will[17]. As a result - the motivation declines.

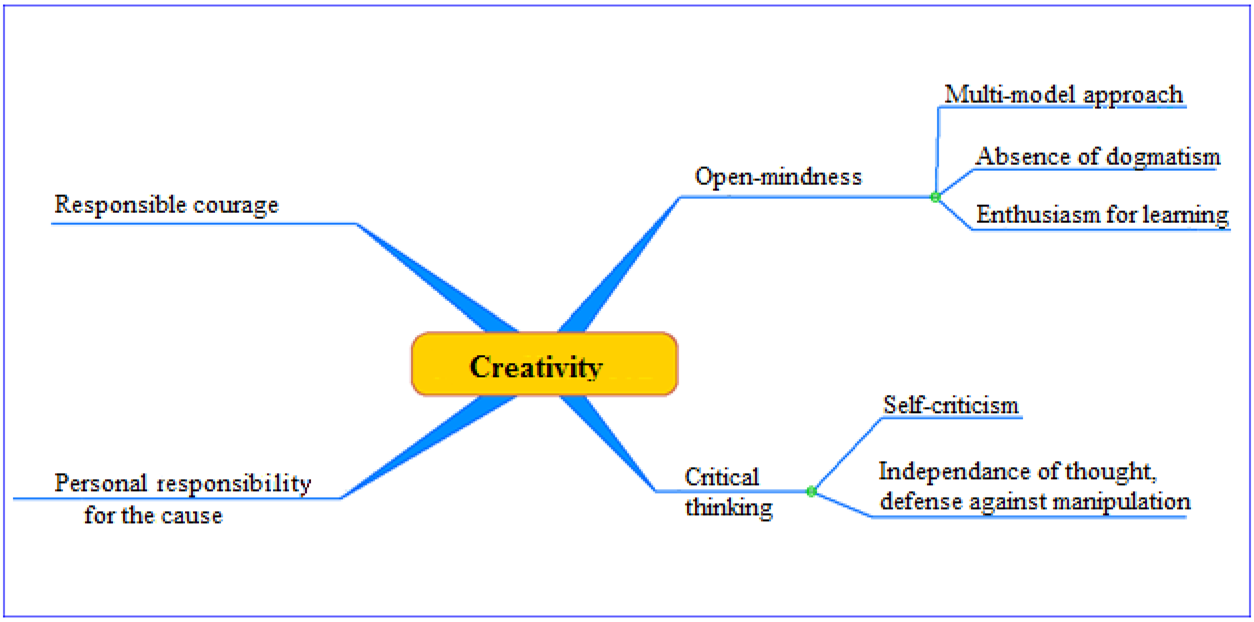
The requirements of the modern times:

- Not memorizing copious amounts of facts, but the ability to link facts to each other
- Not knowing the ready answers, but the ability to ask the right questions
- Not piece-wise, narrow "point" professional skills, but the ability to quickly learn and relearn, a global supra-system understanding of the world
- Etc.

The time is coming when the "displacement of man" from the production systems will become global. People will continue functioning in two fields in which they are not replaced by artificial intelligence: the field of creativity and the field of emotions, empathy and support of each other.

Therefore, the educational system should be aimed at the development of these two meta-competencies. We also believe that an elevated level of creative skills is required for a comfortable life in the new world.

Below is our definition of "creativity":



Pic. 1: definition of "creativity".

Suppose we want to create a new educational system. Where do we start?

[17] *For example, Salman Khan's internet school*

2. NEW PRINCIPLES OF EDUCATION

Let's compile a list of principles of the "new education". For our purposes let's call it TRIZ-pedagogy.

Principles:

- Education is student-centered.
  - This means that the educational system should provide students with a wide variety of ways to learn according to their interests and learning styles.
  - This also means that the educational system should resolve the following contradictions:
    - Education must be broad and comprehensive; however, every person is learning here and now in his or her relatively narrow area of cognitive interests.
    - Education should be universal, but everyone works his or her own way through it.
- Knowledge should be acquired exclusively through creative activities.
  - Knowledge is not important, per se, but in its application. This can be achieved when a person obtains knowledge through project based activities and experiment, not memorization.
- Entire world should be described by a holistic system of knowledge.
  - In real life, everything is interconnected in a holistic system of knowledge. Physics, biology, literature, etc., are merely projections of the infinite world onto conventionally selected planes.
- Without creativity, there is no modern personality;
  - Creativity, widely understood as a person's ability to learn, change and improve his understanding, make decisions in an unconventional situation, solve open problems - makes a person a person. And, besides, in the new modern world, without creativity, there is no chance of being successful and in demand.

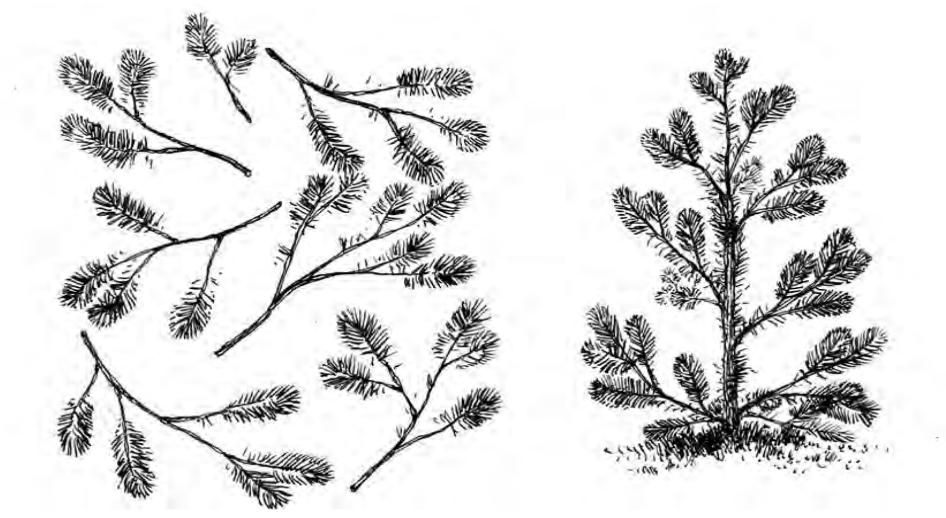
3. WHERE DO WE START?

So, we have defined some principles of TRIZ-pedagogy. Now we shall plan our academic course accordingly.

This course is not at all a complete alternative to traditional mathematics, physics, literature, etc. Rather, it is a connecting link that integrates all these branches of knowledge into wholeness.

Modern schools are only able to teach how to understand the separate branches; however, the whole tree of knowledge lacks its trunk!

Thus, our course should transform a disjoined pile of branches into a beautiful tree.



Now let's find the educational instruments that will help us overcome the contradictions and stand to the principles mentioned above.

The instruments:

- "Open" problems
  - These are inventive, research, forecast and other types of creative tasks.
  - Open problems are usually multifaceted, can be interpreted differently by different people and have different solutions under different conditions.
  - Process of solving open problems usually requires combined knowledge from various fields.
  - Open problems stimulate our brain, help us learn the ways to find innovative ideas.
  - Open problems require additional data search to clarify the conditions.
  - When solving open problems students find a lot of different information that will have emotional associations and that are interconnected.
  - Within the framework of the "theory of open problems", special gateways have been developed, methods for transitioning from an open problem to various concrete-subject knowledge.
  - During seminars teachers stated about 30 didactic values of open problems.

- Lesson – Press Conference
  - It is a form of lesson when new material is introduced based on students' questions. There are teaching strategies for leading such a lesson and for teaching children to ask diverse types of questions.

- Case studies to learn about technical evolution
  - These case studies are perfect educational material that helps children and non-technical adults understand the laws of evolution of technical systems using simple examples.
  - Case studies allow to understand deeply the cause-effect relationships and connectivity of the world.
  - Case studies can include open problems, creative questions, experiments, tests, and subject knowledge.

- Special exercises:
  - Exercises to develop creative imagination.
  - Exercises to practice formulating IFR (ideal final result), using tools to overcome contradictions, working with cause-effect chains and so on.

We emphasize that our goal is to create a course of "engineering" for the development of creative thinking, understandable to adolescents and Liberal Arts students and graduates.

It is such a course, in our opinion, that is objectively in demand in the new world.

Engineering activities in this course are understood as activities to develop, improve both the technical and social environment in all of its richness and diversity.

The engineering course is also intended for the adults in non-technical fields, because its purpose is the formation of certain useful habits of thinking, applicable in a wide range of human activities.

Well, according to our TRIZ tradition, we have outlined a composite portrait of an acceptable solution to our educational problem. What's next?

4. STRUCTURE AND CONTENT OF THE COURSE

Next we should find necessary informational resources. For example, people, who never worked with sciences, should be able to understand our case studies on technical systems. The history of such systems should be appealing, even dramatic, and include solvable open problems for students to work on. For instance, the history of airships is very suitable for a case study. From the first flights of hot air balloons up to our times – the story is well described, dramatic and entertaining, does not have complicated elements and this industry has perspectives for development and application in the future.

Based on the case-study “Breakthrough into the sky” (history of hot air balloons and airships) we can:

- create an academic module that will include creative activities (such as experiments with helium balloons),

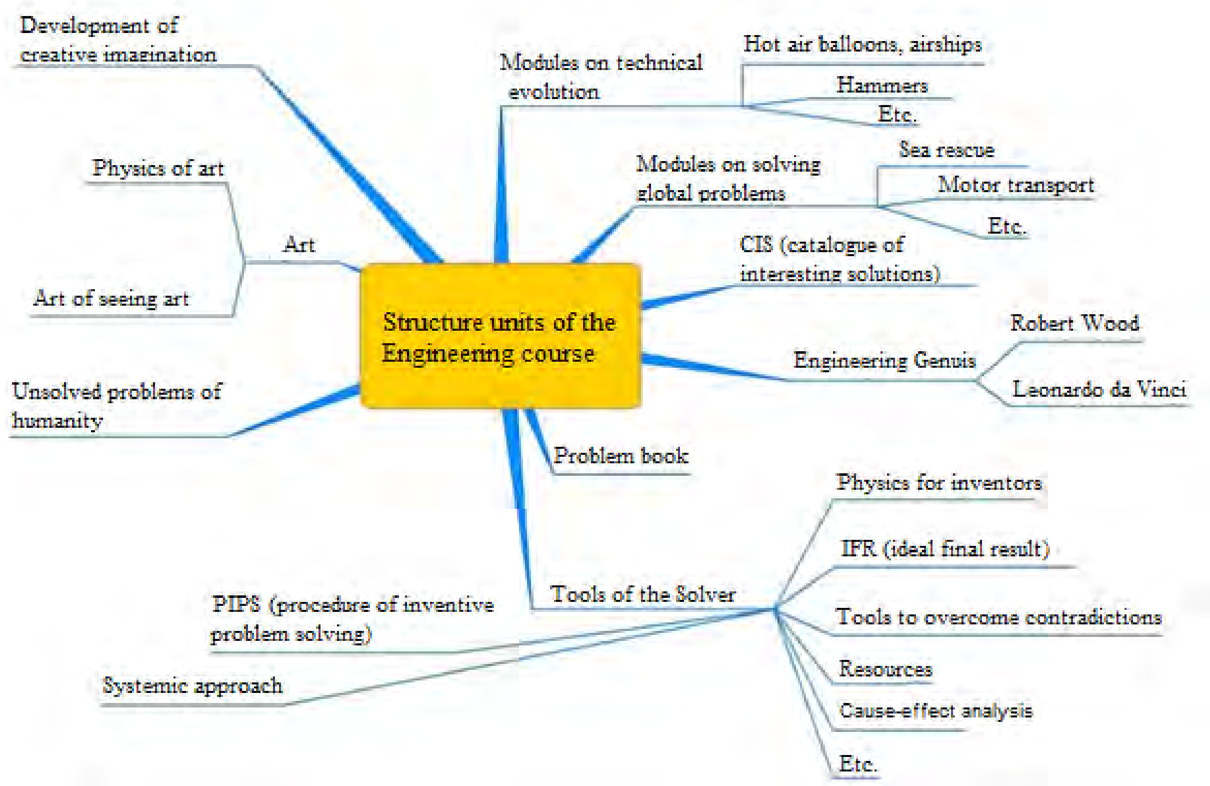
- combine knowledge from areas of history, chemistry, physics, technology and literature

- develop and train open problems solving skills.

The entire course can be assembled from similar modules. Then, depending on the conditions and level of preparation of the children, the teacher will also be able to make his choice, how to collect from this kit what is most expedient in his conditions.

By the way, almost any module can be taught to a rather wide range of ages - depending on the age and level of students’ readiness may determine various course parameters: the time, allocated to each module, the depth of the study of the topic, the inclusion or exclusion of associated calculations.

In a first approximation, the structure of the course can be pictured as follows:



Pic. 2: structural elements of the Engineering course

5. TASK OF IMPLEMENTATION OF THE COURSE AND QUALITY ASSURANCE

However, the development of such a course is only half of the battle[18]. How should we bring life into the course? How will we transform it into teaching practice? Implementation of the course will require resolving several contradictions.

For example:

- Teachers, who themselves were raised in the old educational system, who are used to the “old” ways of thinking, should teach children how to think differently, in a “new” way.

To resolve this contradiction, we need a system of training of future course teachers, online support and certification.

Course materials should be prepared for use by teachers in the most convenient form. These are ready-made presentations for students, and accompanying methodical manuals for teachers, a chrestomathy and other materials.

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[18] *Which is mostly complete.*

6. CONCLUSION

Heinrich Altshuller predicted that sooner or later TRIZ should turn into a "theory of strong thinking". Continuing his predictions, we believe that the future of TRIZ is not in the formation of a caste of super-professional solvers. TRIZ, together with other methods and tools of thinking, will become the basis of the new education system. We see how in recent years there has been a rapidly growing interest in society for such education, that systematically developing creative skills. Let us move together in this direction. We look forward to collaborating.

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OPEN TASKS BY MAKING USE OF WOODEN AND LEGO PLAY BLOCKS

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Abstract

This paper represents the approach and method of using classic wooden play and "Lego" blocks to build "open tasks". Proposed contractions build using play blocks ("gate", "arch", "tower" and "bridge) are far beyond children experience and knowledge, however after few attempts they will manage tasks put to them. These tasks comply with "open tasks" that means children are not informed on how to build individual structures, but after few failed attempts they will achieve positive results. They learn how to individually extract conclusions and achieve determination to reach their goal.

Keywords: open tasks, Building blocks, Lego blocks

1. Admission

To construct open tasks, by using wooden play blocks, the best choice would be to have a set of 52 play blocks. (Fig. 1)

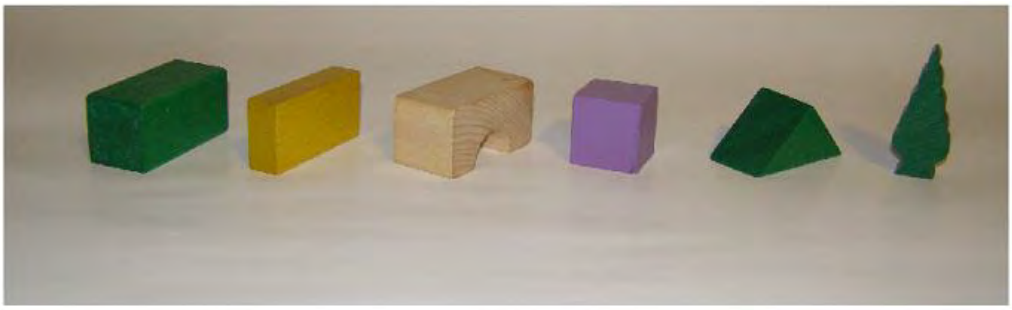

Fig. 1. Play blocks

This set of play blocks consists of different shapes: rectangular, plates, cubes, cylinders and triangular. Some of the basic play blocks have a half circular cuts. Typical play using these play blocks consists generally to erect different structures, simple and complex. Individual elements are built in such way that the blocks are placed on top of each other keeping permanent balance (Fig. 2)

Fig. 2. Typical building made of wooden blocks

2. Building a gate

At the start of the play using these blocks, ask children to build such a gate that small matchbox car can drive through it. The simplest way to perform this task will be gate as seen on Fig. 3. As you can see, the matchbox car cannot be wider that approximately 5cm, as the block closing the gate from the top has to lean on side blocks. This task is simple and most of the time all children will manage it.

Fig. 3. The simplest gate of three blocks

The next step will be to build a gate for wider car. The gate must be 14 – 15 cm wide. This task is more difficult, but simplest completion can look like as in Fig. 4.

Fig. 4. Gate width 12-14 cm

In order to obtain a bigger gap there is a need to move the wooden play blocks apart and place on top more blocks that are slightly advanced. However, for the blocks that a slightly advanced not to fall, they must be pressed from the top by blocks of appropriate weight. This is called „False ceiling principle" used by Egiptions to build piramids and graves. During further attemps we increase expectation regarding width of the gate to achieve best results see Fig. 5 and Fig. 6.

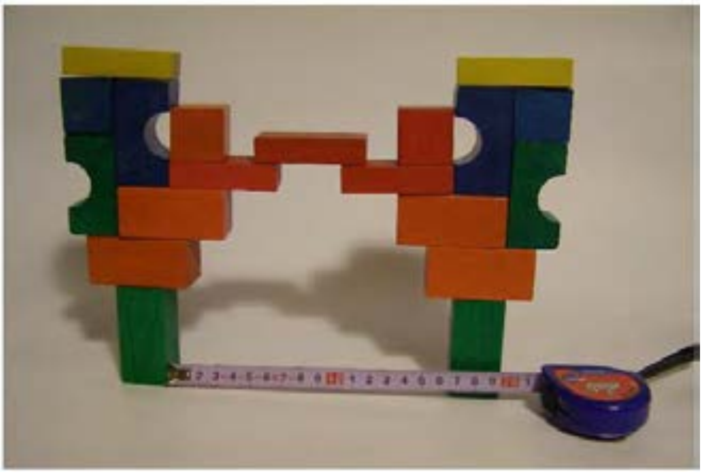

Fig. 5. Gate width 12-14 cm

Fig. 6. Record 22cm wide door

The trick of building these gates depends on that if you would like to move block that is on top of another block you must put weight, so the construction does not fall – picture 06. Children are unaware of the balance principles and they learn it in practice by building structures using play blocks.

2. Building „arches"

The next task is to build arches. The construction consists of the basic single block size 3cm x 3cm x 6cm and further build of it going sideways to achieve the biggest arch, Fig. 7.

Fig. 7. Spanning span of 14 cm

3. Lego play blocks

Lego play blocks provide better composition ability. The way Lego blocks are joint together allows stability and strength of the constructions. Lego blocks are good to build two basic constructions that provide opportunities for unconventional use.

3.1. Tower

Children are given the same sets of basic Lego blocks. They are asked to build the tallest tower that can be done using the blocks given. Children with typical way of thinking will build the tower typically for Lego blocks, they will join them using pegs and slots of play blocks, Fig. 8. 08. However, they will not achieve the impressive height.

Fig. 9. shows that base can be built from short play blocks and the long ones can be joint by overlapping the long elements placed in the base. This way provides possibility to achieve the tallest tower.

Fig. 8. Standard tower from Lego blocks

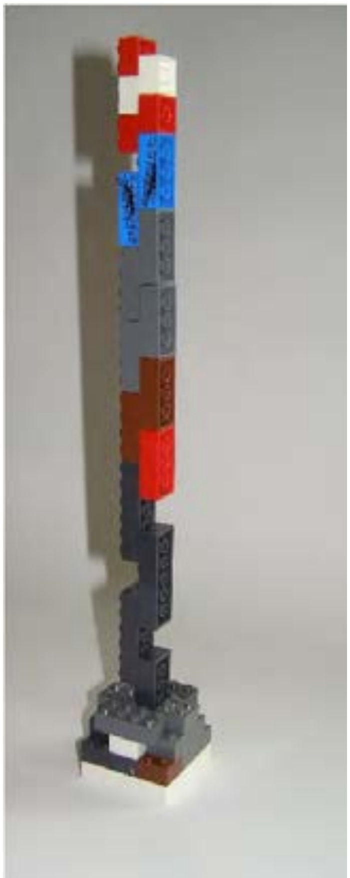

Fig. 9. Unconventional tower construction

3.2. Bridge

The next construction that can be built from Lego blocks can be a bridge. The bases of the bridge are 20 cm apart and child must build the bridge. The bridge then is tested for weight berring by using wooden play blocks

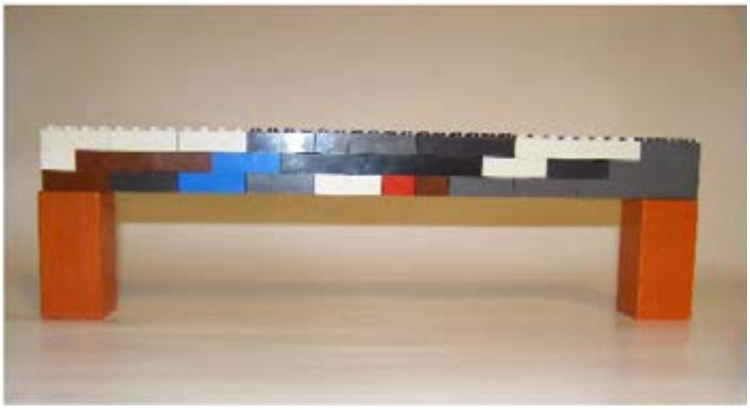

Fig. 10. - Typical bridge

Much better construction is shown in Fig. 11.

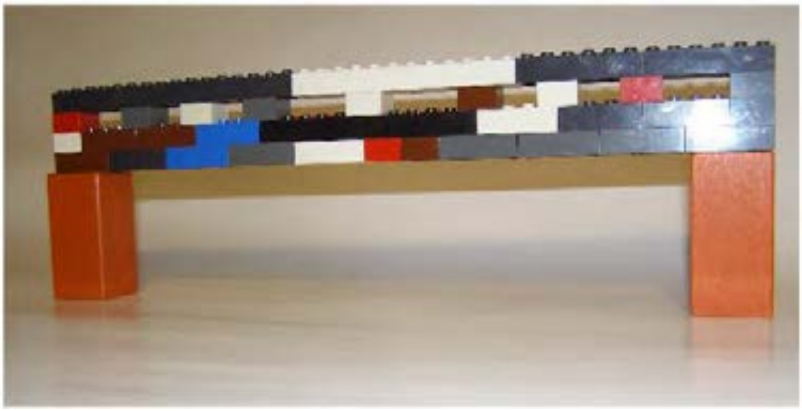

Fig. 11. Much better construction

The bridge is build using principles closer to truss construction. Using the same number of play blocks the carrying capacity is much bigger.

Apart from wooden play blocks and Lego blocks there are other opportunities to be use to play.

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THE EVOLUTION OF ATTITUDES TO ENTREPRENEURSHIP IN PEOPLE (14 -16 YEARS OLD)

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Abstract

The commercialization of life in all forms, competition and race "rats", force to supplement the training of young people with a basic knowledge of market relations, the problems of production and pricing, no idea of the cost of production, selling price, whole sale and retail price. The advertising strategy, market analysis and the position of "our" product in relation to other articles. All of the set asks, both in life and in training, are the "open tasks" of varying degrees of difficulty.

Keywords: business, management, business, calculation, business plan, work, profit, deal,

1. Admission

Entrepreneurship requires a completely different preparation than the standard school.
Imagine that a group of adolescents aged 14-16 years, decides to start a company, and so do some business, that brings the profits. This involves the need to resolve the whole range of so-called. "open tasks", that is, where we do not have the foulest of data, there is no algorithm to solve, and from the analysis we can get few results, then we need to select the optimal one, but unambiguous criteria of this optimization is not known.

Let us take the typical (in the spirit of the TRIZ) way: "from idea to industry".

2. What's the deal?

This is the first "open task". There are, of course, method, based on the analysis of the market, identification of the needs of society and the assessment of own potential. It is the reasonable approach, but not congruent to youth activities. It seems that it is reasonably and relatively easy to start analysis from enumerate on resources group of 3-4 person who thinks about its own business. You can help yourself by using the system operator (Table 1). In the Middle window, type "our" business - not yet know what kind. In another window we itemize elements, which do not depend on the group, but they shape their capabilities. Subsystem - to resource group members, as well as other measures: financial, tools, different equipment, access to the materials i.e. waste from a friendly factory.

Table 1.

System Operator

	Where we live: town, village, nearby businesses, cultural and educational institutions, local community, wholesale centres and retail outlets, natural features: pond, wicker, etc.)	
Students at a lower secondary school	Our business: manufacture of toys	Owners of youth-owned business involved in manufacturing of children's kites
	Our resources: computers, utility room, woodmaker's workshop once owned by grandfather, one of students has woodworking skills, another student plays the guitar, etc.	

Based on the above outline, a type of business undertaking can be singled out. A school class – one of those participating in the "I'm active – I'll become an entrepreneur" programme chose, once divided into three groups, three business undertakings:

A – Manufacture of children's toys – flat kites (Fig. 1)
B – Manufacture of children's toys – box kites (Fig. 2)
C – enactment and cabaret group to provide artistic setting for weddings, conferences, etc. (Fig. 03)

Fig. 1. Flat kite

Fig. 2 Box kite

Fig. 3. Duel

3. The initial "business plan"

Youth Group is going to produce flat kites known as "Malayan". The group returns to the "sub-system" and checks what prices these kites can achieve in the shop. On line search survey shows that the prices of the "flat" kites the size of an average of 60 x 40 cm with drawstring and tail range from 4 to approx. 40 PLN.

We take a mean price, that is about PLN 22, and we realise that this is a net price. If we take a retail markup of about 25%, the wholesale price would be about PLN 17.6. A wholesaler has its markup, too. It is in the range of 20%, so the selling price (“our” price) will be about PLN 14.66. The following components must fit into that amount:

- cost of materials,
- cost of labour
- profit
- overhead costs – organisational and general
- payroll tax
- social and health insurance contributions

This is a simplified set of elements that make up a selling price. Presumably, youth-owned business is exempted from VAT.

Young manufacturers notice that they pay PLN 7 "for nothing" on each kite. They realize that they pay a retail and wholesale markups if they buy materials (sticks, paper, cord) at retail outlets, they overpay in the sense that they pay retail and wholesale markups.

"Operational" activities

Group wants to reduce the costs: searches the resource of Subsystem and looking for direct suppliers, that is, manufacturers of the different components of the kite.
Sticks; DIY store sells sticks 100 cm long at a price of PLN 4 apiece (Fig. 4).

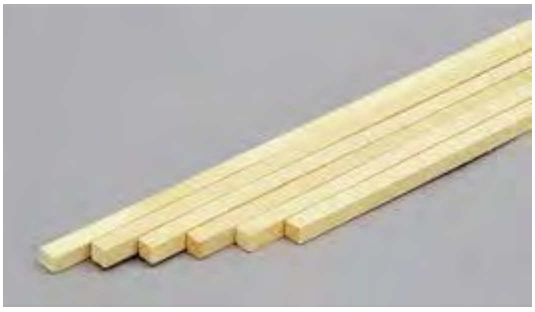

Fig. 4, DIY store sticks

A kite having 60 cm x 40 cm dimensions can be made from them, and then no waste material is produced. Because the cheapest kites are sold at very low prices (PLN 4 a piece), a bigger ones should rather be manufactured, e.g. 90 cm x 60 cm, which will allow for keeping up a price of PLN 22 or event make it a little higher. DIY store sticks would not be economical, then, because two sticks will be needed to build one kite and waste material will be generated: 30 cm and 10 cm long sticks, for which one has to pay at a DIY store.

A contradiction comes up: a kite should be bigger than 40 x 60 and should not be bigger, because the use of two DIY store sticks will contribute to a higher cost. This is, as termed by TRIZ nomenclature "a physical contradiction." Such a contradiction can be resolved "in time." In the situation discussed here, it just means that it will be best to order sticks of the proper lengths from a manufacturer (woodmaker's).

Now, there comes another contradiction: a woodmaker's says that he can make sticks, but not fewer than 1,000 sets, because a smaller quantity would not be profitable for him! It means that **we need to have a lot of sticks and pay "much", but we cannot pay for 1,000 sets, so we can pay "little!**" A total amount is an impediment. A solution can be:

- substitution of sticks with a considerably cheaper material,
- finding a manufacturer who will agree to make a smaller quantity of sticks.

And again we take advantage of super-system resources. We can remember that there is a big pond at the outskirts of the town with its shores covered in wicker. We know, from observation of wicker furniture and baskets, that wicker sticks are strong, flexible and can be used as a kite frame!

We figure out how wicker can be obtained: it may be someone's plantation or maybe it is managed by municipal greenery services? If it is not a plantation, but rather wild-grown plants, we can have, most of the times, wicker for free (Fig. 5)

Fig. 5. A bundle of wicker sticks

Tail. The most labour-intensive element of a kite is its tail if it has a “classic” form. i.e. coloured tissue paper tied with a piece of cord. A loop must be tied for each piece of tissue paper, then a piece of tissue paper is fed into a loop and it is drawn. For a kite 90 cm x 60 cm, a tail has to be about 3.5 – 4 meters long, which entails a necessity of tying up about 35 – 40 pieces of tissue paper (Fig. 6). They have to be tied up at even spacing. After all, it is a labour-intensive piece of work! And we want to have our costs reduced. **A tail has to be effective and spectacular, but its making must not be labour-intensive.** A look at different tails let us realise that the quickest thing is to make three or two tails and fix them to three corners of a kite, each of them having a few long (1.2 m – 1.5 m) strips of paper or ribbon (Fig. 7.)

Fig. 6. Classic tail

Fig. 7. Simplified tails

4. Summary

The small piece of analysis shown in this paper on problem regarding commencing production

– as it seemed -simple product, illustrates the complexity of the task to take the production of "anything". Young people aged 14-16 years old do not have information on issues such as: the construction of the retail price and what are: selling price, whole sale price, margins retail and whole sale,

- how to choose sources of supply for commodities to maximize profit,

- what labour cost calculation: what is direct labour, overhead, indirect costs, what further components make up the selling price, and soon.

Although it is difficult to require young people to have a knowledge of TRIZ methodology, however, even such a fragmented analysis shows that the base of the TRIZ methodology can be very helpful in solving different problems, with the characteristics of open tasks.

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TRIZ FOR SCHOOLS

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Abstract

For about three years now Philips is supporting schools to help students to be more creative and inventive via an organization called Jet-Net. In a number of projects training materials for both, the students themselves, but also the teachers are being designed, tested and improved.

The present paper will briefly outline the history of these activities so far, and move on to explain some of the results and techniques that are being used, and the results we achieve in class..

Keywords: TRIZ, Schools, Education, Teaching materials, Pupils, Netherlands

1. Introduction

Starting in 2014 with a Philips sponsored project that was conducted with a number of secondary schools in Eindhoven, Christoph Dobrusskin and Hans Baaijens got involved with using the TRIZ tools to teach creativity and problem solving at schools. Since then they have introduced in excess of 400 pupils and teachers to TRIZ, and how it can help school children to be more creative to solve problems in a systematic and innovative way. Mandy Stoop got involved in 2016 from the viewpoint of integrating these activities more structurally in the curriculum of the education of teachers. This is supported by the STEM Teacher Academy, a program that supports high school teachers and teacher educators to intensify the collaboration between businesses and education.

The initial reactions from all involved parties was extremely positive. It was realized that TRIZ as a “Meta-Method” was able to bridge gaps between the theories that are taught in most classical school topics such as physics and the practical applications of that knowledge to solve specific problems.

It also became rapidly apparent that the teaching material needed to be adapted not only to the respective age of the pupils, but furthermore to the relatively short duration of lessons in schools. Furthermore, the example cases used needed to be carefully selected to be attractive to students with a wide variety of interests and inclinations.

From the initial work-sessions with pupils it was also quickly realized that, to reach a wider audience and to have a real impact on what pupils learn, TRIZ would have to be taught by the teachers themselves, or even be included in school curriculums, rather than a few individuals from industry trying to teach pupils by themselves.

2. TRIZ teaching activities in Schools, in the Eindhoven region of the Netherlands

Since 2014 we have been actively involved with a large number of activities in the Region of Eindhoven to bring the TRIZ way of thinking to school pupils from high schools, and we have been able to teach about 400 individuals, both pupils and their teachers (see Table 1).

Table 1

TRIZ teaching activities for secondary schools in the region of Eindhoven since 2014

Year	Project title	# of pupils or teachers	Comments
2014	Crowd ID	30	Project for pupils with pre-university education, focusing on finding ideas for new products
2015	Creative Problem solving workshop	80	Creative problem solving workshop with 80 teachers of the Lorentz Casimir Lyceum in Eindhoven, a pre-university high school
	TRIZ “Masterclass”	20	A TRIZ Masterclass with school pupils of Brainport Schools in Eindhoven
	Creative Problem solving workshop	15	Creative problem solving workshop with teachers from Brainport Schools in Eindhoven
2016	Creative Problem solving workshop	100	Creative problem solving workshop with teachers from Heerbeeck College in Best
	Creative Problem solving workshop	30	Creative problem solving workshop with teachers that are being educated, from universities in Nijmegen, Tilburg and Eindhoven
	TRIZ “Masterclass”	20	A TRIZ Masterclass with school pupils from Brainport Schools in Eindhoven

2017	Creative Problem solving workshop	10	Creative problem solving workshop with teachers from the Eindhoven area
	Creative Problem solving workshop	10	Creative problem solving workshop with lecturers from the Fontys University for teacher education.
	Creative Problem solving workshop	80	Creative problem solving workshop with first year high school pupils at the Odulphus Lyceum Tilburg
	Creative Problem solving workshop	15	Creative problem solving workshop with the management team of Brainport Schools in Eindhoven

In addition to these dedicated teaching activities we have formed a DOT, a Docenten Ontwikkel Team (Teacher Development Team) with several teachers from the above schools, and we meet several times a year to discuss our teaching activities and collect teaching materials on the subject for further general use.

3. TRIZ training material for schools

We have found, during the above activities that, on a fundamental level, the ways and tools of teaching TRIZ to teachers compared to teaching TRIZ to school children are identical.

3.1. Teaching the theory

The first activity in teaching any method or tool is – of course – to teach the theoretical background. There are a number of attention points we try to address at this point:

Firstly boredom. Faced with learning theory many pupils, young ones or old ones immediately think of listening to hours of dry explanation. We counter the dangers of boredom by using a combination of storytelling and exercises. Storytelling, particularly when combined with a riddle or a mystery keeps the tension of the listener and is a compelling way of bringing across the message, while at the same time keeping the audience's attention. Rather than listening and trying to memorize bullet-point after bullet-point of information, the information is strung together in a logical sequence of events that lodges itself into the mind of the listener and is much easier to remember [1].

The second attention point is relevance. Here we need to look at the background of TRIZ as a meta-tool to science. TRIZ set out to be the science of problem solving [2], but it acknowledges that it can only do that when based on the fundaments of other sciences, be that chemistry, physics or engineering (Fig. 1).

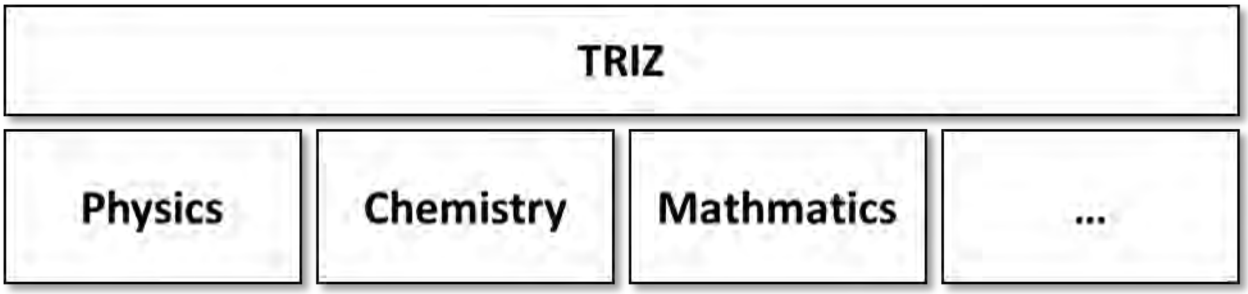

Fig. 1. TRIZ as meta-tool to science

Looking at that in the context of school education it is readily apparent that, for the school kids, the foundations of most of these other sciences are just being laid. In our teaching approach we therefor start by teaching the fundamental notions, the mind-set of TRIZ without going into the deeper details and tools. This is also well in line with the experiences of G. Altshuller [3]. And, in addition, to cover the innovation aspect rather than just invention, we extend the boundaries of classical TRIZ by including elements of Design Thinking [4]. To make this concrete, the three core TRIZ related thinking steps that we always want to teach are:

1. Know your client / situation
2. Analyse your problem
3. Build on already available knowledge to solve the problem

As succinctly pointed out in some literature on TRIZ education, we know two basic types of problems, closed ones and open ones [5]. Closed problems have well defined parameters and generally there is only one way to solve them. However, in the real world open problems prevail, whereby not all parameters are clear and many different solutions ca be found. On a very basic level the three previous steps are sufficient for successfully introducing the structured way of thinking of how TRIZ approaches creativity and problem solving, a way of thinking that is so particularly well suited for those open problems. And based on the maturity level of the students we can add tools at a later stage, be that Ideality [6] for understanding the ideal required end-result for the client, cause-effect-chain-analysis [7, 8] for analysing the problem situation or the 40 inventive principles [8] as the accumulated knowledge of how, on an abstract level, people have solved problems in the past.

3.2. Exercise cases

One crucial aspect of teaching TRIZ in our opinion is teaching by doing. If the theory isn't put into practice by the pupils, it will not be anchored in their minds. The first step is teaching the basics, getting the pupils familiar with the topic.

In most cases, the TRIZ theory is first explained in a few slides and using an example case, and the students are then tasked with using the theory on another case. For example, we often introduce the Cause-Effect-Chain-Analysis (CECA) in a short presentation, exploring the real underlying causes of a simple case, for example a headache. Afterwards the students are confronted with a problem they are familiar with - for the Netherlands we often use a bicycle that has a flat tire, a case that is also explored in [7] and we ask to create a CECA for that case (Fig. 2). For students of a younger age we teach methodologies such as: "five times why" or: "what, where, when, how much" [10] instead, with the aim to "upgrade" them to the CECA at a later stage.

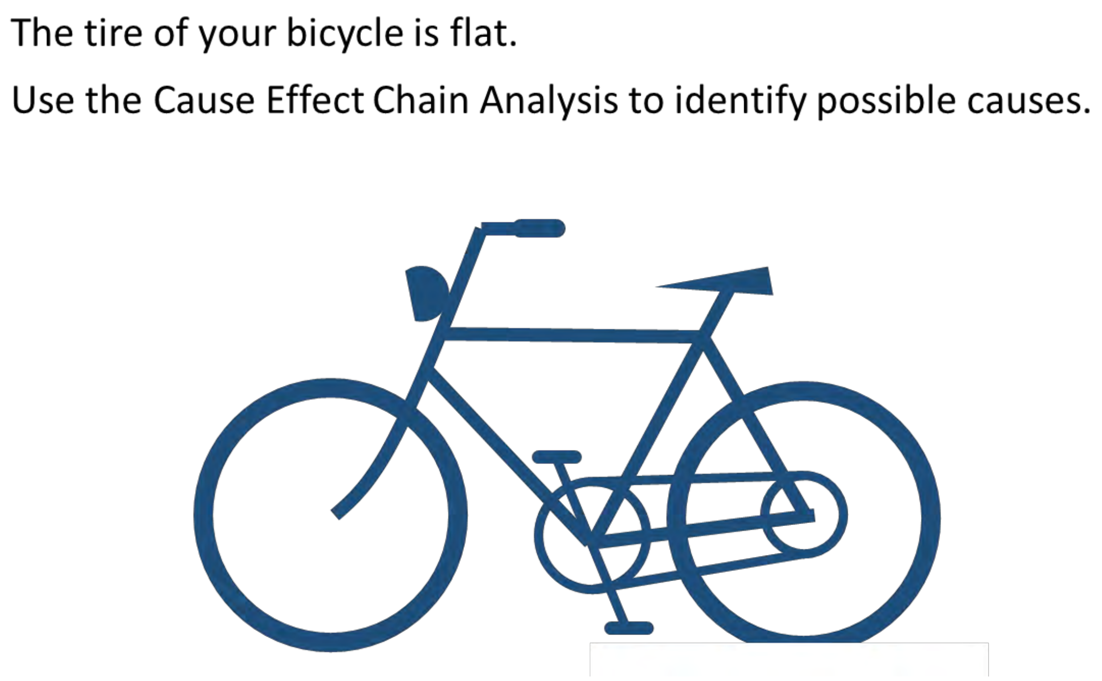

Fig. 2. The case of the flat bicycle tire

For some school subjects, seemingly unrelated to TRIZ, there are opportunities for a supporting role here: For example, one of the teachers that participated in our TRIZ course teaches German. She asked her students to research certain aspects of TRIZ, and to give short presentations on those aspects – in German. A typical task could be, for example, to give a short explanation of one of the 40 Principles with examples illustrating that principle [11]. In her experience this exercise was well appreciated by her pupils, as they learned something useful in addition to the language per se.

Another simple exercise that we often use is to first explain the 40 principles and then to ask the students to search for examples of the use of these principles in a given area or object. We often use objects like a bicycle that are familiar and can be easily studied and touched. Students find this exercise exciting, they can get out of the classroom, they can do the exercise together in small groups and one sees the excitement of sharing discoveries while they work, and all the way they gain a deeper understanding of the 40 inventive principles. This way of working is, in fact, also being explored in TRIZ education for engineers [12].

To show how easy it is to apply the 40 principles to real-world problems we have a set of exercise cases that we use in short creative sessions. Typically we tell everyone that they are now employees of a company producing an object, and one everyone is familiar with, for example a shoe or a door. The pupils then get a selection of the 40 principles, two or three are normally more than sufficient, to create new ideas on the topic selected. Even after less than half an hour of creative working time, a lot of interesting ideas have normally been created, ideas that everyone agrees would not have been created using simple "brainstorming".

To illustrate that TRIZ has applications that reach beyond the typical technical areas, we have, in addition a number of cases from other fields. For example we often present the case of the newspaper: A local newspaper has a fixed number of pages, whereby, a certain number of the pages should be editorial material and another number are reserved for advertisement for local shops. A new shop has just come to the area and would like to advertise, but all advertisement space is already taken by existing shops. To print additional pages, would require a significant and non-realistic extension of the paper. What could be done to satisfy the advertisement needs both, of the already existing shops as well as the new to the area shop?

In any case, once the pupils have gained some understanding of the basic principles of working with TRIZ, they are put towards integrating the different steps and work on projects from the start. Luckily, in the Netherlands, most of the schools have time in their curriculum for these kind of projects, and commonly these projects span more than one teaching subject, and require the student to create, design, and build something.

In the case of the Brainport schools, for example, classes visit different companies throughout the year, get presented with specific issues of each company and are then asked to work out potential improvements. In this case the exercise case is provided by the company, and the students have to apply the general approach of understanding the clients need, analysing the problem in depth, and then come up with ideas targeted as solving the problem. And it is in those projects that we see the integral use of the aforementioned way of working: First understand the needs of the client, then analyse the specific problem to explore the parameters, and finally to find creative solutions to those problems. We have done those exercises a number of times and have found that TRIZ can truly act as a backbone to string together the different elements of successful innovation in a structured and logical sequence.

4. TRIZ integration in the school curriculum

Within the Netherlands there are many discussions about what should be taught to our pupils. We do understand that for future careers the factual knowledge of classic teaching topics is not sufficient as the basis for a successful career. In this discussion the thinking about 21st century skills [13] is broadly adapted. But teachers are still working on the fundaments and didactics to develop this skills by pupils. In international research it appears that Dutch students are relatively less motivated at school [14]. Lots of teachers are discussing this topic and are looking for ways to improve that. Platform 2032 [15] is an initiative from the Dutch government that tries to combine these thoughts by developing a new curriculum, in a fluid and dialogical way. Within this discussion ownership for pupils and creativity seems to be a part of the anchors of improving teaching practice and make it more future proof. This is underlined by the reactions and experiences of teachers who are confronted with the TRIZ workshops and who have applied it in their lessons.

TRIZ therefore may not be a teaching subject for the curriculum, but a teaching strategy for enriched didactics. That makes it possible for a broad adaptation within schools. The method is designed for fostering creative thinking and problem solving, and that makes the method very accessible for STEM related topic in the high school programme [16]. As the didactic approach for problem solving using TRIZ is suitable for all subject and contributes to the stimulation of creativity and ownership in all subjects it is a solid strategy to implement TRIZ in all teaching topics in schools.

As mentioned, teachers are the key to teach pupils the TRIZ way of thinking. So teachers must be trained to use the method. To accomplish that we have started to develop trainings for teachers. Within these trainings teachers are stimulated to use the principles within the classroom and share what they learn by doing. This course is going to be spread within the member of the NVON [17], the Dutch Union of Teachers in Science Topics. This Union counts about four thousand members. The next phase is to start a connection with the Dutch Educational Corporation and FVOV [18]. These are umbrella” organizations for teacher Unions like NVON that connect to the other topics.

The aforementioned courses are organized at Fontys University of Applied Science [19]. This university provides a teacher education program, its students are trained to become teachers. In the academic year 2017-2018 a new teacher education Program will start: Science and Technology. For this program teachers-in-education will be trained in use the TRIZ method in their teaching practice.

So far the teacher educators have had an introduction to the TRIZ workshop in April 2017, and they were very enthusiastic. They immediately saw the richness of the TRIZ method for the educational Program and were interested to be trained themselves in more detail. And that is what we are organizing at the time of writing this paper. In this way the TRIZ way of thinking will be used at the educational program level of science teachers.

5. Summary and way forward

In summary we can say that we have set a first successful step in bringing TRIZ and its structured ways of thinking to the secondary education system in the Netherlands. Teachers and pupils alike, are enthusiastic and can see the advantages of TRIZ, particularly, but not exclusively in science related topics. TRIZ also fits in perfectly with the declared interest of furthering creative thinking and structured problem solving in the education system [13].

Looking at it in pure number terms, we have at present only reached a very small percentage of the target population in the Netherlands; 0.5 % of the teachers and even less % of the pupils. This also sets the challenge that is currently being addressed as outlined in Chapter 4 above: how to increase the reach structurally across a much larger percentage of the school population.

And finally we are happy to exchange views, learnings and experiences with other interesting parties in similar situations.

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TRIZ IN THE TEACHING OF THE POLISH LANGUAGE

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Abstract

Life and observation of newspaper articles, journalists' statements in the media, politicians' statements, indicate a growing problem with the communication of Poles in Polish. Existing curriculums are ineffective, overloaded with content. Neither they support language correctness, nor do they teach how to elegantly express oneself. It seems that application of foreign languages teaching methods to the teaching of Polish language, as well as making use of a number of linguistic tasks (expecially „open tasks") could improve the situation.

Keywords: open tasks, translational tasks, translation of poetry, oratorio competitions

1. Admission

A decline in reading is a global phenomenon. There are exceptions like Finland where young people read a lot without being forced to do so. It brings about a reduction in effectiveness and precision of communication. Globalization in all aspects of life and the pressure of information technology media: computers, tablets, mobile phones facilitates communication and the exchange of information. Unfortunately, it results in the impoverishment of national languages and their contamination with English words. Obviously, one may argue whether it is good or not. Throughout the ages, there were periods of, for example, domination of the Latin language, later on replaced by French, being a language of aristocrats and diplomats. In the public life in Poland, we can witness an increasing number of loanwords from English. Some of them are reasonably justified like the word *computer*, as it is just inconvenient to say *digital electronic machine*. It holds true for most IT terms. One can say jokingly that only the mouse was saved. After all, it's called the mouse in English, too. A wide spread use of computers among young people has brought about the use of abbreviated words like *w porzo, spoko, pozdro*, etc.

Words like *oki, sorki,* etc., that only seemingly are English are coined.

A sad phenomenon is violation of basic grammar rules of the Polish language - nie wiadomo, czy młodzi **będą potrafili** instead of nie wiadomo czy młodzi **potrafią**; **mi** się to podoba instead of **mnie** się to podoba; poproszę o **tą** książkę instead of poproszę o **tę** książką, etc.

2. Suggestions for changes

Language at schools. It seems that the following changes are required:

a) The general methodology of the teaching of the Polish language should be similar to principles applied in the A short necessity is the change of the system and methodology of the teaching of the Polish teaching of foreign languages.
b) Teaching grammar should be reduced to an absolutely required minimum.
c) Separation of the teaching of the history of the Polish literature from the teaching of the Polish language. Teaching of the literature might be linked to the teaching of painting, music and sculpture and the resulting subject might be called *History of the Polish culture*?
d) The teaching of the practical use of the Polish language in various circumstances and in a variety of topics, communicated both in writing and orally.

The situation might be improved by the introduction of Polish language teaching with the use of the TRIZ methodology (Theory of Solving of Innovative Text-Based Tasks). The essence of the TRIZ Methodology - Pedagogy is to mobilise thinking to the widest way in all manifestations and circumstances. The foundation of the methodology is open-ended tasks. These are problem-based tasks in which

- there is not a complete set of input data;
- there is no ready-made solution;
- there are many solutions of similar correctness.

3. Translation tasks

There are a great many options of developing and solving open-ended tasks in the teaching of the Polish language. A good practice is translation of texts in foreign languages into Polish, especially the ones belonging to the classical poetry, that means the ones having rhymes, rhythm, caesura, metaphors and similes. An attempt at rendering these elements in Polish, especially an attempt at rendering *melody* of a poem is a difficult yet interesting task. The literary skill shown in such translations is not of importance. Other elements are important. In order to prepare a good (even very school-like) translation, one must have an in-depth understanding of the original text, taking account of allusions, references to classic texts in the original language and the culture of the country in which the language is a prevalent one. Fragments of translations of *Ulysses* by Maciej Słomyczński or *Harry Potter* by Andrzej Polkowski can serve as examples of translation solutions. The two translators were faced up with a language full of words and expressions far from everyday language. They had to find Polish equivalents of them.

Polish writers caused a lot of trouble to translators of literary works into foreign languages. It suffices to mention neologisms by Sienkiewicz such as *prosto, jakoby ktoś sierpem rzucił*, by Wańkowicz - *siądźka, kuwaka, chciejstwo* and many others, by Lem - *świdraulina, elektrybałt*, a whole range of names of devices and apparatus of the future, etc.

An adventure with translation of such contents is about the necessity to go deep in intentions of an author of an original text in order to render it in Polish.

In order to train primary and secondary schools students, works of literature have to be carefully selected, to match young people's abilities. Therefore, such an intermediate step can be the “translation” of contemporary Polish poems so that they have the form of classical poems, i.e.

the ones having rhymes, rhythm and other stylistic elements. Young people often make a point about contemporary poetry - *No rhymes, no rhythm, no sense*. Let's have a look at a poem by T. Różewicz:

Księżyc świeci

Księżyc świeci
pusta ulica
księżyc świeci
człowiek ucieka
księżyc świeci
człowiek upadł
człowiek zgasł
księżyc świeci
Pusta ulica
Twarz umarłego
Kałuża wody.

The poem was re-worked into a rhymed one that meets formal principles of rhymed poetry, yet with every effort to retain its meaning.

Księżyc świeci II

W poświacie księżyca,
Po pustej ulicy
Biegnie spóźniony człowiek,
Biegnie, upada,
Coś do siebie gada;
Powietrze łapie z wysiłkiem.
Jeszcze jedno westchnienie
I ostatnie spojrzenie
Na zamgloną w półmroku ulicę,
W bladym świetle księżyca,
Obojętna ulica,
Kałużą wody twarz bladą rozjaśnia,
I to światło księżyca
I ta pusta ulica,
Są jak świeca wraz z życiem wygasła...

An interesting discussion may ensue: to what extent the rhyme meets the concept of the author of original work and where it deviates from it because of the requirements of rhymes and rhythm.

A good exercise is translation, done in groups, of small fragments of a text in prose or poetry from a foreign language into Polish. Beforehand, the class is divided into three groups - Group One translates a text in a foreign language into Polish and passes it to Group Two. Group Two translates the text from the Polish language back into a foreign language and passes it to Group Three. Group Three translates the text that had been translated in a foreign language by Group

Two into Polish. Finally, translations into Polish are compared. The class analyses the reasons for deviations between the two versions.

A greater number of like and similar tasks can be developed.

Group work, using the Google translate service. Group One uses the Google translate service in order to translate a text in a foreign language into Polish. Group Two translates the same text on their own. Two groups discuss the two translations and try to explain why there are differences.

4. Literary tasks

Gap filling is a good introductory task. Students are given a text with gaps. They have to fill in the missing sentences to make the whole meaningful and logical. An example:

a) A deafening noise of a drum mill made a conversation impossible.
b) …….
c) How nicely you designed it, Dear.
d) ……

The dots should be replaced by simple sentences, extended to include other parts of speech apart from the verb and the noun, to make the whole logical.

Another literary task can be giving the class a text on any chosen subject that needs completing. The resulting text should be logical and look like it was written by one author from the beginning to the very end.

Another suggestion is *An Oratorical Contest*. Participants should give short speeches or lectures on an assigned or a free topic. The class and a teacher assess stylishness, linguistic correctness and contents of the whole speech.

Students can be trained in speaking by staging criminal or civil trials. Cases known from the media or self-developed can be used. Prosecutor and defence counsel's speeches are important. Other elements of a trial are of no importance.

It is worth reminding that rhetoric and dialectics were an important element of education in Ancient Rome.

There was a time that orators, Cicerone being the most famous one, became a cult object. His contemporaries said that when Cicerone defended a man who was kept a prisoner without a cause – all those present were weeping! Similarly, when he indicted a criminal, the crowd was willing to tear the defendant apart. Today, no one will teach rhetoric, but the art of expressing one's thoughts in a clear and substantially proper manner is and will continue to be treasured.

5. Conclusions

The foregoing outline is a slight opening of the door leading to a spacious area that can be extended depending on a teacher's inventiveness, but also students' inventiveness to some extent. Not all students will be able to carry out all tasks presented here. Tasks must be designed taking into account abilities of students in a class. However, it is recommended that tasks go slightly beyond students' abilities, that they are not all too banal. Solving easy tasks does not provide satisfaction that is required for a proper process of education.

It is obvious that the introduction of the TRIZ methodology must not interfere with the core curriculum. However, a teacher has a certain degree of liberty in teaching curricular contents, and it is worth taking advantage of that liberty to implement some element of the TRIZ pedagogy.

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TRIZ INVENTION SCHOOL FOR THE CHILDREN AND THE YOUTH

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Abstract

TRIZ techniques have been well-known to solve technical problems of technical systems in Korean industry since it was introduced in 1996. TRIZ has attracted big interest as it has helped typical engineers creating new ideas over the psychological inertia of the experience and knowledge. The authors have focused on the power of TRIZ to connect creativity with scientific knowledge, which motivated the authors to create a new material to guide children and youths to 'learn science and technology' via inventive thinking process. Education materials used in so called "TRIZ invention school" for the children and the youth were established based on the context knowledge of Korean society and culture. Classical TRIZ has been a little bit modified to be familiar with Korean children and youths. Other discipline knowledge, for example, literature, history and science were organized with thinking programs. One of thinking program, 'size magician' came from STC operator of classical TRIZ and OTSM-TRIZ. The authors defined 4 different spells of the 'size magician ', increase magic, decrease magic, accordion magic and pick-a-boo magic. After the teacher suggests the 'card' of magician's spell and specific object (for example, aunt) to the students, the students are asked to think to change the object according to thinking direction of the ' magician card'. Control questions for magician spell cards are as following: what happens if the size of whole aunt or part of aunt becomes bigger than a building? What's the good, bad, interesting feature of such change of aunt for aunt and for others? Since an invention is a technological solution to meet human desires, the authors include a program to emphasize the other people, animals, object in Korean fairy tale and conventional technical system. Trying to understand the situation of other person or things, children and students can enhance the ability to discover invention points of something. '4-Step Thinking Process' based on ARIZ promoted the students to think 'impossible problem toward invention idea' more rational ways with real shape training aid. The authors designed a lot of training aids for all classroom session. TRIZ invention school shows a program how Korean children can easily learn and apply inventive thinking way as well as multi-discipline knowledge to practical problems. Even if this program has been organized based on the personal motivation of the authors, Samsung Electronics has evaluated the potential of this program so big to apply it as a social contribution program to students of Yong-duck Middle School in Suwon-city in 2016. The authors and Samsung Electronics will continue social contribution program based on TRIZ invention school every year.

Keywords: TRIZ; invention school; children; youth; Korean culture; teaching aid; group learning; education; creativity

1. Introduction

1.1. Motivation

Creative problem solving technique TRIZ derived from Jewish Russian Altshuller [1] has been known to be useful for industrial engineers to solve technical problems in engineering field. Samsung in Korea has actively utilized it as a methodology of research and development since 1998 [2-3]. The authors have validated the effect by applying TRIZ for a long time in various industrial fields [4], for example, recognizing faces in the camera video has been successfully solved [5] and embedded in brand-new Samsung's smart phone, galaxy S8. Even if TRIZ tool developed by Altshuller is extremely useful for engineering problem solving [1,6]; however, it was designed for adult persons, which makes it difficult for the junior students to learn. Khomenko et al. [7] suggested a useful material for children educational for Russian and European, however there was cultural barrier between Europeans and Koreans especially in practice examples. As TRIZ was established in European culture not in Korean culture, where TRIZ logics and case examples are little bit strange for young Korean student to emphasize. In other sides, TRIZ Nolite [8], a Korean TRIZ research group, provided a Korean fairy-tales linked with TRIZ agendas, which was familiar to Korean culture, but it had limitation to promote holistic thinking ability of children and youth aligned with many learning agenda, for example, linguistics, scientific knowledge, art, collaboration experience, invention practice, ethics and so on. The authors have intended to remove cultural differences between classical TRIZ and Korean culture as well as to develop holistic thinking power based TRIZ and other useful agenda for little students, which were summarized in novel learning materials, so called TRIZ invention school [9-12].

1.2. Scope and Objective

Whole materials were designed not to be instructed by the teacher one way but to trigger intensive communication between students-students and students-teacher. The authors aimed to attract the students to discover the contradictions in the objects easily encountered in daily life. TRIZ invention school uses contemporary Korean words which go well with the children and the youth, instead of authentic TRIZ terminology. It presents the problems that young people can encounter in their lives and enables them to link scientific knowledge they have with the problems. The authors published "TRIZ Inventions Classroom" [11-12] to deliver TRIZ experience to Korean youth, and verified by actual field classes. Following 4 experiences are what the authors want the student to learn. To provide these 4 experiences, the authors designed all the contents, teaching aid, teaching methods, and so on.

- Collaboration and communication experience
- Knowledge and examples expressed in familiar terms and situation
- Experience using TRIZ knowledge
- The "awakening experience" of problem solving through the utilization of scientific knowledge and background knowledge that the students already have.

2. Results and Discussion

2.1. Whole Structure Design

Against to the Korean education tradition used to solve given problems and compete for points against colleagues, the authors wanted for the students to collaborate and communicate with their colleagues not for just solving the problem but for formulating new problem. To deliver this goal, a new teaching method based on project driven group learning was suggested where the participating youths can think and express themselves. Instead of presenting theories first, the authors suggest challenge situation first. The theory follows presentation session of the participating students about eh challenge as a summary. The authors keep the order of following procedure: 1) suggest challenge, 2) group work for the challenge, 3) presentation of the group work, 4) theoretical background to the given challenge.

The TRIZ invention class consists of 3 main parts: (1) a course to train language ability and observation ability of things as a fundamental thoughtivity, (2) a course to learn various analysis methods, (3) a course to exercise authentic TRIZ methods. Since it can be tedious to repeat the same or similar subject to students, we constructed this process to be mixed with each other and educated so that students can maintain their interests.

One course can be carried out for 1 to 2 hours with 3-6 group composed of 3-6 students. Each course consists of 8 sections designed to give students an appreciation for each principle and to familiarize them with theory and practice. These 8 sections were designed based on the flow that the elementary school students accepted without difficulty through more than 3 actual teaching experiments.

(1) Introduction problem: Students can solve it without methodology

(2) Introduction of principle: Explanation of principle

(3) Principles of Practice: Principles of Practice

(4) Introduction Problems - Principle Connections: Solving Introduction Problems by Applying New Principles

(5) Introduction Issues - In-depth Discussion: Discussing the practical solutions to the introduction issues together

(6) Deep Problems - Applying the Principle: Applying the Principle to Deep Problems

(7) In-depth issues - in-depth discussions: Discussing the practical solutions to in-depth issues

(8) Theorems and Challenges: Theorem on principles and additional challenges

TRIZ Invention School Program consists of 14 classes that are suitable for the 3-month course of Korean traditional after-school classes. Teachers can select and reduce classes according to their circumstances. Currently, the TRIZ Invention School is completed with 28 classes for 6 months, and the authors continue increasing classes. The textbook for students, teaching aids for teacher and the standard teaching method are complementary to the invention school instruction and are constantly being reinforced through on-the-job teaching experience.

Table 1

Contents of TRIZ Invention Class - Book 1

Class name	TRIZ/Learning items	Class name	TRIZ/Learning items
1. Size Magician	STC Operator	8. Learn Nature	Biomimetic
2. Order Magician	STC Operator	9. Metaphor and substi-man	Function, Resources, Feature transfer
3. Secret of Magic	Scientific effects	10. Making fish trap in camping park	Resources, Scientific effects
4. Empathy	Design Thinking/empathy	11. Story wheel	Storytelling
5. Part and All	Multiscreen, function	12. Segmenting	Inventive principles: segmentation
6. Clustering	Multiscreen, classification	13. How many ways to make water	Scientific effects
7. Imagine best	Ideal system	14. Thinking up steps	ARIZ for junior

Table 2

Contents of TRIZ Invention Class - Book 2

Class name	TRIZ/Learning items	Class name	TRIZ/Learning items
1. Many windows	Multiscreen, resources	8. Conflict finding in fairy tale	Contradiction
2. Finding cause	Causality analysis	9. Extraction	Inventive principles: Extraction
3. How it works	Function analysis, su-field model, scientific effects	10. Secret of grandfather's glasses	Physical contradiction, separation principles by space
4. 100 features	Attribute analysis Investigation attitude	11. Secret of airplane wings	Physical contradiction, separation principles by time
5. Inventing Poem	Literal creativity	12. Inventing New Chinese Alphabet	Linguistics
6. Master of quiz making	Resource analysis, metaphor	13. Master of summary-making	Abstraction, Linguistics
7. Both sides	Conflict finding, resource analysis	14. Drawing mysterious dream	Artistic Expression Skill, ideal system

"Book 1 - Class 4. Empathy" introduces training observation ability and empathic ability of problem, "Book 1 - Class 5. Part and All" provides for the student to learn functional analysis which is an analysis method of TRIZ's technical system, "Book 1 - Class 1. Size Magician "defines a new way of defining the problem as an STC operator," Book 1 - Class 12. Segmenting " presents the method of division within 40 inventive principles, " Book 1 - Class 14. Thinking Up Steps " leads the student to follow the entire problem solving flow of ARIZ.

Figure 1 shows various teaching aid material for TRIZ Invention School activities. Story wheel, thinking up steps, magician spell cards, object cards, inventive principles, story cards, and so on, were originally designed by the authors. Using these teaching aids, young people are requested to perform various activities described in the textbooks.

Figure 1. Various Teaching aids for TRIZ invention school

2.2. Activity Case 1. Magician's School

Class 1, Chapter 1-2 Size Magician and Order Magician are related to the STC (Size, Time, Cost) operator of TRIZ, which is effective for problem definition and viewpoint change. Referring to OTSM (General Theory for Strong Thinking) developed by Khomenko [8], the authors modified the TRIZ TTF technique to meet the level of Korean youth 's interest, and created a new conceptual activity so called Magician's school.

After defining the characteristics of objects and situations such as size and order, the students try minimizing and/or maximizing with the aid of magician card denoted in Figure 2. The students analyse what would happen when the size (for example) maximized and discuss their own thinking with other students in the same group. There are 4 different magicians as following: size magician, time/order magician, price magician, and feature magician. The size magician can perform four magic spells – increase magic, decrease magic, accordion magic and pick-a-boo magic.

To be friendly with Korean students, the authors have created original characters, Gyuri, a Korean girl and Ein, a Korean boy who are twins and presented an original story of a situation that is very familiar to Korean youth as following:

> *"Tomorrow is the day of school picnic. The teacher promised to give her goods to whom bring the funniest lunch box. Gyuri and Ein asked their mother to pack a funny lunch, but*

> *their mother answered that she would make that lunch box when Gyuri and Ein by themselves came up with idea of the most funny lunch box. The D-day is tomorrow, but Gyuri and Ein could not come up with an interesting lunch box idea yet, Gyuri and Ein decided to ask Dr. TRIZ to help them."*

Under such circumstances, the participants might choose "lunch box" as the central object and focus on "kimbap-Korean seaweed roll", the most popular menu of Korean students' picnic. Students are asked to express their thoughts through the activities of the group. A large paper, multi coloured marker pens, post-its, and other materials can be used for group activities, and one assistant teacher for each group can help them to carry out their activities in accordance with the instructions of the main teacher. If the students are old enough (usually middle school student), one of the students might be assigned to serve as an assistant teacher. The order of activities is as following.

Figure 2. Teaching aids for Size Magician

1. How do you list the features of the selected object? In particular, we list the characteristics of spatial size. The students will summarize the size, contents, and how to make common kimbab.

2. Choose the appropriate [Size Magician] to apply from size magic cards. For example, "Increase magic".

3. What good result could be delivered by the size magic? The size of kimbap can be changed in both length and diameter. Make sure you think of as many good points as possible and make a presentation when changes occur.

4. What bad features or problems could be brought by the size magic? What are fatal problems if they grow in size? Rolling, cutting might be tough.

5. What interesting event could be brought by the size magic?

6. How can I maximize 3? How can I solve the problem of 4? Where is wasteful if we can make good use of 5?

The process step of 3-6 is a modification of the PMI(plus-minus-interesting) technique [13] embedded in full thinking process, which naturally guides the students to have balanced viewing habit as well as to enhance ability to analyse conflict. This balanced critic is one of critical ingredient to promote innovation and invention environment of group work, the authors made a ground rule of critic as following: "praise first, critic follows." Through this process, students could internalize appropriate critics skill.

2.3. Activity Case 2. Story Wheel

A "story wheel" is a process of creating a plausible story by combining keywords that have been never connected to one another before. The wheel can be freely rotated by the hand power of a child. When the wheel suggests a hero, place, and object material word from a familiar fairy tale, the student starts making a plausible story based on the chosen keywords. Through these activities, students can train their language/composition skill. The number of sections of a story wheel might be around 4 or 5., The students could draw a picture based on the novel story just created by the group. The following is an example of a triple story wheel.

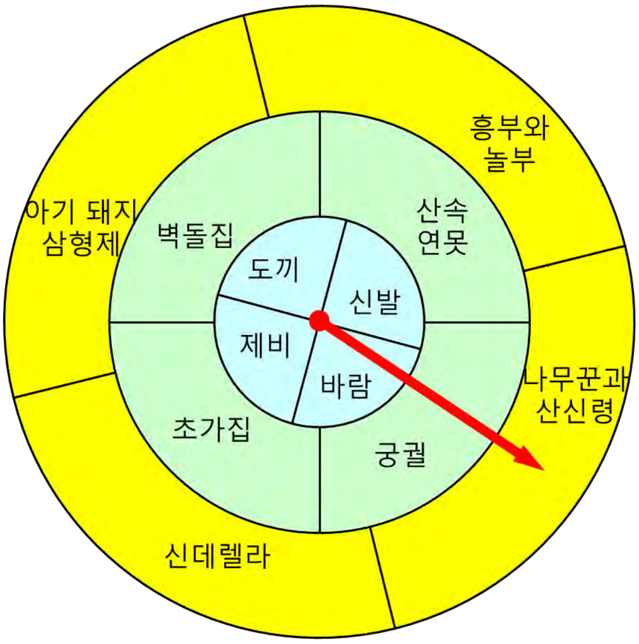

Figure 3. 3-layer story wheel

Three different fairy tales for triple talk wheels as following

- Heungboo-Nolboo - a traditional Korean fairy tale
- Three little pigs - a Well-known western fairy tale
- Woodman and mountain gods - Korean traditional fairy tale
- Cinderella - a Well-known Western fairy-tale

Structure of tripe story wheel

- Outer wheel: the leading character in a fairy tale
- Middle Wheel: Place where the main character was
- Inner wheels: important things in fairy tales

Let's choose the absolutely new combination.

 Main character: Heungboo-Nolboo

 Place: humble straw house (Place for Heungboo-Nolboo)

 Object: shoes (the main object of the story of "Cinderella")

A newly created story might be as following:

"Heungboo, who was kicked out by Nolboo, had a hard time for eating and living, and by chance he found pretty shoes at a shoe store in the market. He went to the place where he could learn to make shoes. There, Heungboo has worked hard for many years to make cool shoes, and gained big enough name to make luxury shoes, he became a big rich."

Original Heungboo-Nolboo fairy tale is as following: when Heungboo lived in humble straw houses, he healed a broken leg of a swallow. The swallow returned the grace by a magic seed, which grew big fruit with great treasure in it. The newly made story changed to Heungboo to see the beautiful shoes and learn how to make it, and to build blessings on his own. It is the main activity of the story wheel to make a new story, to express it with a picture, and to present it while using the existing hero, place, and object material.

2.4. Analysis of Activity Application

Group Learning

Under the general educational environment in Korea, there is a teacher who instructs more than 20 students with the help of media teaching aid and physical teaching aid. The teacher presents contents and questions, students answer and ask questions, and there are a few chances to learn a way to discuss their opinions between teachers vs. students as well as between students themselves. One of the biggest problems of the current educational environment is that the education focuses on just enhancing individual's knowledge capacity and testing it clearly. It is difficult to deploy collaborative learning or in the current educational environment. Students learn something and gain more points but they are lack of collaboration ability and questioning ability. Innovation and invention could be brought not by one person but also by collaboration works of many people, but school learning environment is far from driving real innovation.

Since the authors have witnessed how important team play is in real innovation situation, we designed all the activities of the TRIZ Invention School as a team play material. To encourage learners familiar with team play from early childhood, the assistant teacher per each team was asked to give positive feedback to the students who contribute the team appropriately as well as to coach the student who shows inappropriate attitude for the team activity. When the lower grades of elementary school students (under age 10) had trouble to be friendly to play as a team member, individual lesson were delivered. In the case of junior high school students (over age 10), after 1-2 rounds of trial and error, they became familiar with their own team roles, and their team play ability was enhanced turn by turn, which implies that TRIZ Invention School can grow up collaboration and presentation capacity for innovation.

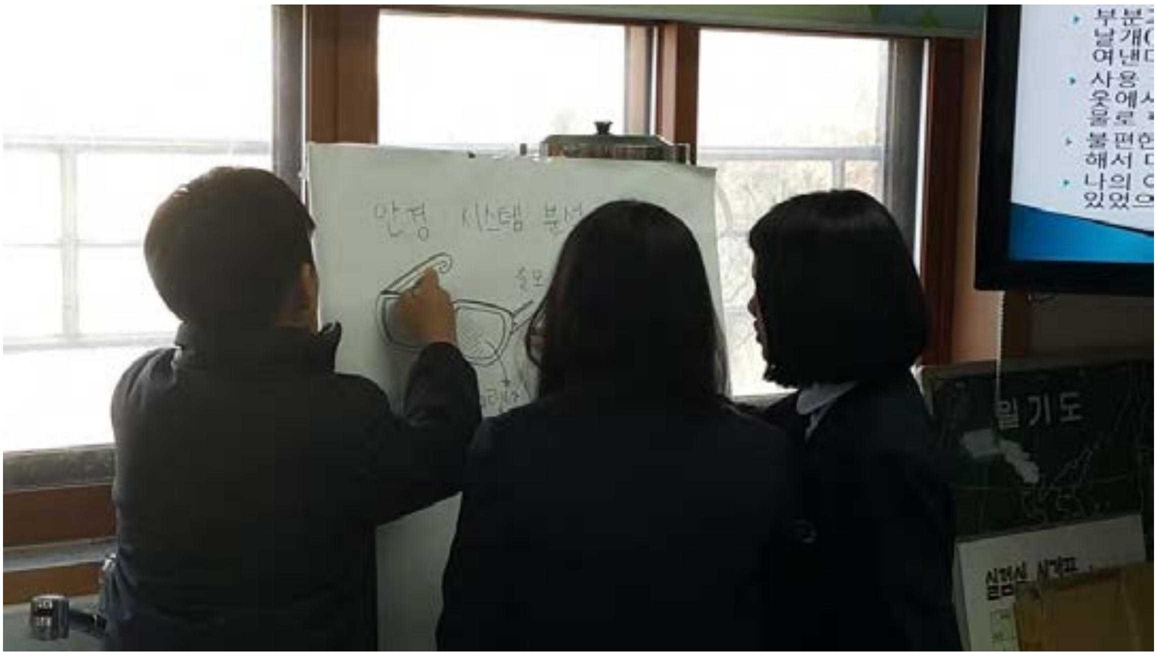

Figure 4. Students in group learning session (Part and All Class)

Magician's School

In the general education environment in Korea, students are usually asked to solve problems with the correct answers they have learned before, which imply usual students have little chance to learn how to define an open problem and solve it until they become grown-ups. One of the common cultural features of Korean society is the vertical hierarchy, which means top orders, bottom follows. In this vertical culture, it is considered as a disturbing activity to the hierarchy to raise new issues or identify new problems, so there are few chances to train the ability to raise new problems for common people.

The fact that the pace of change is faster than that of any other era is synonymous with that problem comes to us in the blink of an eye literally. It is a big tragedy that they are lack of ability how to know what kind of problems is going to happen. The reason why the authors placed STC operator at the forefront of all classes with an interesting name for children called magician school is based on the reflection on the Korean vertical culture. STC Operator is a process of learning how to define problems, and it is useful for not only passively solving a given problem, but also for developing the ability to change the problems condition in advance.

Story Wheel

The story wheel is an activity to reinforce storytelling capacity, which is an essential capability to combine resources to create a new solution. It can be fully applied if the authors tried it on the basis of the fairy tale that they have read before. Under ordinary Korean educational environment, it is difficult to learn how to make your own story based on given materials, so there are many grown-ups who are not able to making different stories with same ingredients. As innovation is the process of externalizing and realizing new stories that they have never thought before, story making is a very important language skill to make future image. If the students are familiar with using the given story wheel, they can challenge to make their own ones based on different/same stories.

Figure 5. Story wheel group learning

3. Summary and Conclusions

TRIZ is a wonderful tool for the ordinary engineer who are familiar with European culture with enough scientific knowledge, which makes Korean middle school and elementary school students hard to understand and learn. In this study, the authors intended to modify classical TRIZ agenda to provide education material suitable for Korean children's understanding level with various knowledge agenda which should be provide to the students: literature, history, storytelling, scientific knowledge, foreign language, empathy, ethics, and so on. "TRIZ Invention School" includes the efforts of the authors to remove cultural differences between classical TRIZ and Korean culture as well as to develop holistic thinking power based TRIZ and other useful agenda.

Korean students could learn to see things from various perspectives, to find problem solving directions, and to develop their ability to solve problems with limited resources without big mental discrepancies with the aid of TRIZ Invention School. TRIZ Invention School materials has been run for various workshop programs for 1)Samsung Advanced Institute of Technology, a summer science workshop (mixture of elementary and middle school), 2) Dongtan Christian International School students (elementary-middle school), and a TRIZ Invention Workshop (1 ~ 6th grade mixed class), 3) Creative Invention lecture (adult subject) opened at Yonsei University and Alternative Lifelong Education Center, and 4) TRIZ Invention Creativity Class for 1st grade of Suwon Youngdeok Middle School, where they have confirmed that all the participants could learn to apply core knowledge of TRIZ to re-define and solve novel problems.

The authors aim to have a system that enables Korean young people to use TRIZ not only to learn TRIZ well but also to make useful inventions based on TRIZ knowledge background. The authors will continue creating more exciting and challenging programs that enable Korean youth to make more creative inventions through TRIZ by ensuring the specific linkage with the actual invention activities.

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TRIZ PEDAGOGY AS THE BASIS OF THE EDUCATIONAL PROCESS

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Abstract:

School is a large and living organism. Like any organism, it can grow, evolve or die. When there is a dream, an idea, an understanding of what and how to implement, and with whom, the dream becomes reality. TRIZ pedagogy became the «cornerstone» (system-forming factor), which allows the School to develop. TRIZ pedagogy – a celebration for teachers and students, through which introduced an innovation and technology training conditions for creative education.

***Keywords*:**

TRIZ pedagogy, functional system-based approach (FSA), systemic creative thinking.

1. Introduction.

The World Economic Forum in Davos in 2016 was remembered for its special attention to the issues of education and development - as a pledge of solving humanitarian problems that exist today and will arise in the future. There will be new categories of professions that will replace the old ones. But, most importantly, Davos' participants state, the list of skills required in both new and old professions will change. Forum analysts presented skills that are relevant to a successful career and will be important in 2020 [1]. The first three skills are integrated (systemic) problem solving, critical thinking and creativity. There aren't such things in school education.

In the school education, there is a huge problem - no system in the delivery of school material. Therefore, the pupils do not form the systemic thinking. The training program is artificially divided into subjects. As a result, each subject describes its own surrounding reality. In addition, at school they teach disparate facts and require from pupils to learn definitions that were formulated by someone long ago. This is not productive for the development of the students.

For us, the development of a child means forming his new abilities. «Ability is something not reducible to the knowledge and skills. The new ability gives child the possibility of free action on the situation and its transformation. The word «ability» comes from the word «method». The appearance of ability means the appearance of new modes of action, that is, new mechanisms of action [2]. The material of the school lesson does NOT develop a pupil, but those actions that are done with this material do.

What actions can develop system thinking and create new abilities of the pupils?
This question was answered in TRIZ.

2. Materials and methods.

Already for 16 years at the Private School «EidoS» we use the author's model structure of the Functional Systems-based Approach in the education developed by E. Gredynarova (hereinafter FSA).

A functional system-based approach in the education is a method of learning and a way to describe artificial and natural things, objects and phenomena in the world (hereinafter the objects). This is a tool to assist in the systemic analysis of objects, subjects, and phenomena.

It can be effectively employed when working with concepts and terms. The model structure of the FSA assists in structuring pupils' existing and newly-acquired knowledge [3].

A graphical representation of the model structure of FSA is presented using eidetic (image) techniques – the employment of pictograms reflecting the five modalities of perception (visual, auditory, olfactory, gustatory, and tactile) which can be easily understood and remembered by pupils of all ages.

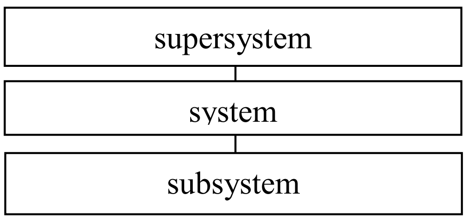
Important facts: Using the model structure of the FSA allows to form the qualities of a creative personality directly during the educational process. It is essential to shorten the time for mastering the basic educational subjects, and to release time for creative work with information. Applying the model structure of the FSA, the pupil acts as a researcher.

Using the model structure of the FSA enables teachers entering a new level of activity - the level of creating of their own educational and didactic techniques. Sometimes it is done together with children.

The founder of TRIZ Genrikh Altshuller wrote: «Thinking is not systemic. People did not have time in the process of evolution to develop a systemic vision of the world. If the problem says «a tree», a person sees the tree. Exhaustive search of variants begins. The tree grows a little more, a little less ... Often on this all ends: the answer is not found, the problem is found to be unsolvable.

The quotation above describes ordinary thinking.

The talented thinking simultaneously sees three different screens: a supersystem (a group of trees), a system (tree), a subsystem (leaf)» [4].



To organize system thinking, Genrikh Altshuller suggested including an object or a subject in a nine-screen scheme, showing the past and the future at each level. Nine (at least nine!) screens systemically and dynamically reflect the system and dynamic world.

«Therefore, a person can learn the systemic approach only by fundamentally reconstructing his/her thinking, which is obliged to consider the system at once and simultaneously in the whole complex of the problems» [4].

According to the definition by academician Sergei Maximenko [5], Director of the G.S. Kostiuk Institute of Psychology at the National Academy of Pedagogical Science of Ukraine, The functional system-based approach in education engages at the 'genetic entity', and 'cellular' levels, which enables the development of all structural components of cogitation.

Mechanisms of cogitation – mental operations (comparison, analysis, synthesis, classification, abstraction, generalisation, arrangement). Forms of cogitation – schematic, verbal-logical, productive, theoretical, practical. Features of cogitation – independence, criticism, flexibility, depth, self-consistency, speed.

System thinking, creativity is the need of modern man. And so the school must teach these (system thinking, creativity) to children.

TRIZ differs from all cogitation development technologies by answering the question, 'How to develop thinking?' That is to say, TRIZ provides the means (tools) for developing cogitation. We find confirmation from the well-known psychologists, for example, P.Ya. Galperin said that it is necessary to improve the means by which pupils engage in mental activity:

1. It is necessary to improve the means by which pupils engage in mental activity.
2. The performance of mental work depends on their availability [6].

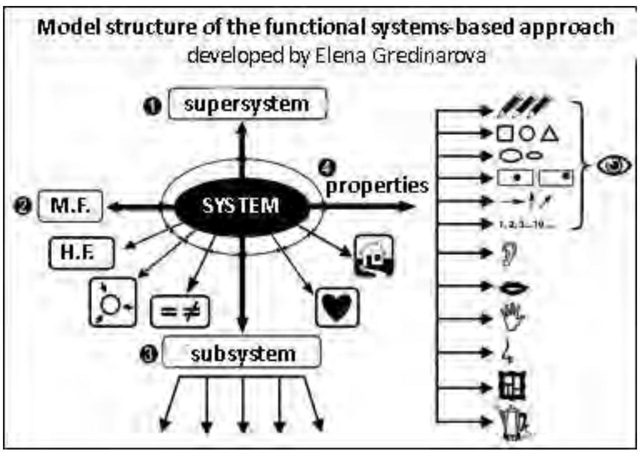
He believed that «The introduction of psychological means in mental activity is necessary. Their introduction will transfer responsibility for mastering the educational material from a child to the improvement of teaching and educational methodologies». Therefore, we believe that TRIZ is a psychological tool for the development of the child in school.

3. What and how do we do it in EidoS?

By combining the knowledge of age psychology and pedagogy with the TRIZ and Eidetic techniques, we have developed a model structure of the FSA for the use in the educational process which formed the basis of the dissertational research on establishing psychological conditions for pupils to master their learning activities. The experience of these innovations is described in 27 scientific papers.

The basis of the model structure of FSA is the structure of nine screens of G.S. Altshuller.

A graphical representation of the model structure of the functional system-based approach is presented using eidetic techniques –pictograms. It not only makes it easier for school students (especially younger ones) to remember the structure of the system, but also makes the process of working according to the structure interesting and fascinating.



FSA is used at various lessons when working with concepts and terms.

The model structure of the functional systems-based approach is a graphical representation of the main components of the system and their interrelations for the complex study of an object, phenomenon, or educational topic.

The model structure of the functional system-based approach allows for the following:

- The description of subjects and objects.
- The definition of concepts.
- To identify significant connections and relationships between the object's elements and identify hidden connections.
- To compare an object with other objects, and create analogies and metaphors.
- To improve objects and subjects.
- To conduct a genetic analysis (examination of an object or subject in development).
- To create a large number of associations in different categories.
- To compose puzzles.
- To create stories and essays.
- To put together a structural response to a lesson or exam.
- To create an algorithm to present information.
- To create algorithms to solve non-standard problems.

4. Progress of work under the model structure of FSA.

1. Which system does the studied object, subject, or phenomenon fit into? What is it a part of?

2. What is the main function of this object? What purpose does it serve?

3. What elements is the object made up of? What has gone into it?

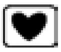
4. What is hidden (latent) function of the object? What else can be done with it?

5. What are the object's properties? Colour, shape, size? What is its sound, taste, touch, smell? What material is it made of? What is its state of matter (solid, liquid, gas)? Other properties may be singled out (depending on the purpose of studying the object).

6. A comparison with other objects. What do they look like? How are they different to from each other? Finding analogies and creating metaphors.


7. Where is the object located? What is its place? A genetic analysis of the object: the story of its origin and development.


8. Different points of view on the object. What is it for people who interact with it (depending on age, social status, nationality, profession, etc.)?


9. What is your emotional relationship to the object? Do you like it, or not? How would the object need to be changed for you to like it? Movement: what is the object sensible to? [7]

For the teachers, the initial means of learning, transfer of information and the way to assimilate the material is a functional-system based approach, through which they create an algorithm for the submission of any task, exercise, and theme. The help of the teacher and the psychologist to the pupil consists in the fact that they think over the details of the delivery of the subject material (information) and its assimilation using FSA.

5. Example of a Literature lesson.

Consider the literary concept of «fable».

The main function of the literary system «fable»- to teach, highlight human vices. The epic is the supersystem of the fable. For the «fable» system, the next group of subsystems is distinguished: heroes, author (narrator), prehistory, instructive history, morality.

For example, analysing a fable as a system, the pupils of the 4th grade distinguish such genre attributes:

- Volume: small
- Form: prosaic or poetic;
- Literary and artistic features:
  - Instructive, allegorical;
  - Contains artistic and visual means (epithets, comparisons, metaphors, hyperboles, allegories);
  - Has a continuity of stories.

The definitions of main function, supersystem, subsystem and properties give an idea of the essence of the studies subject, object or phenomenon. Sometimes these are not enough to perceive the complexity or to understand the system. In order to relate the analyses system and other systems, it is necessary to expand the field of study.

For example, when studying the literary genres, it is advisable to compare the «fable» and «poem» systems.

Table 1.

	Fable	Poem
Supersystem	Epos	Lyrics
Main function	To teach, highlight human vices	To influence the feelings of the reader
Subsystem	Author (narrator)	Author
	Heroes	Lyrical hero
	Prehistory	Thoughts, feelings of the hero
	Instructive story	Main idea (intention)
	Morality	
Form Volume	Prose, verse Small in volume	Poetry: stanza, rhyme, intonation, volume Small in volume
Artistic-visual means	Epithets, comparisons, metaphors, hyperbole, allegory	Epithets, comparisons, personifications, metaphors, symbols, «minus-reception»
Others	Instinctiveness Allegiance Continuity of stories	Alliteration and assonance Bright images

After such comparison, the pupils summarize what is similar between these genres and how they differ. Based on the description of the fable as a system, they can compose an algorithm of composition of their author's works in this genre.

In the genetic analysis of a particular fable, the development of an action can be observed. The «fable» system, for example, can be evaluated from the position of an author as a product of creativity, a way of self-expression; from the position of a publisher - as a commodity;

from the position of a reader - as a way of learning new information, getting food for reflection or emotional experiences. Moreover, an adult reader and a child will evaluate the book in different ways: for the child the form of the book (format, illustrations, text size, etc.) is more important, while for the adult - the content (informational content) is.

In the emotional component, one can trace the pupils' personal attitude to the content of the fable, the argumentation of their assessment. If any element or feature is not liked by the student, he/she can come up with his own plot, that is, come up with a way to improve the object.

6. Algorithm for determining the content of concepts.

On the basis of a separate supersystem, main function, subsystem and properties, a meaning of the concept may be defined by a series of figures indicated in the plan.

1. The supersystem.
2. The main function.
3. The subsystems.
4. Properties and characteristics.

The approximate formula to attain a definition is as follows:

The system is … (1-supersystem), which is designed to ... (2-main function), consisting of ... (3-subsystems), which possesses ... (4-characteristics and properties).

The definition should reflect the fundamental elements and characteristics that distinguish this system from other systems belonging to the same supersystem. In formulating the definition, it is important to specify only those parameters that the system possesses, without mentioning anything irrelevant. In each academic subject it is necessary to define concepts. For example, what is a circle, triangle, sea, electric tension, noun.

Let us, for example, look at the algorithmic definition of 'an airplane'. An airplane is a form of air transportation intended for people and cargo over long distances and at high speed. It has a frame, engine, control instruments, and wings. Different airplanes have different levels of capacity, and are made of metal.

7. Let’s give an example of riddles composition in primary school.

Together with the school students, after analyzing the existing riddles, on the basis of the model structure of FSA we distinguish the next types of riddles:

- Riddles related to main function (the purpose for which an object was created)
- Riddles related to genetic analysis (evolution of the object)
- Riddles on characteristics
- Riddles related to 'its correct place'
- Riddles related to its constituent parts (subsystems)
- Riddles related to metaphor [8]

Together with the pupils we create an algorithm for compiling a riddle.

Examples of riddles written by 3rd and 4th year primary school pupils:

On the main function:
It washes, it wrings, it dries. Mom is very friendly with her.
On the subsystem and features:

With a mind, but not a person, with a screen, but not a television, with a mouse, but not a mink.
On the genetic analysis (evolution of the object):
There was a simple stick. It has found a platter and went to dig a treasure.
On the metaphor:
Furry hot water bottle sits on your lap.
On its place:
Sweets, chewing gum, a bracelet, a phone, a ticket, some nuts, a card, a stone, keys, chocolate, a small toy rocket, all these can be found in a... (pockets).

8. An example of using the model structure of FSA at a history lesson.

The pupils are divided into groups; each group receives a text and a selection of historical sources: memoirs of contemporaries, government decrees, newspaper articles, etc. Next, each team discusses and formulates the theses, filling out the elements of the model structure. Then the teams share the information they received and discuss the reasons for the appearance of historical phenomena, for example, totalitarianism, its types, signs and functions. The teacher acts as a moderator. At the end of the lesson, the whole topic is studied and framed in the form of the model structure of FSA. The pupils receive the homework to find different points of view about this topic and to express their attitude to this topic and find additional information about.

9. Examples of the practice of TRIZ pedagogy.

Such methods and exercises of TRIZ pedagogy as Yes-No, Good-Bad, Morphological Table, Method of Phonetic Associations, Press Conference, Ability to ask questions and Open Problems, are used in «EidoS» not only in TRIZ lessons, but also in subject lessons [9], [10], [11], [12]. Our teachers know and use these methods. Creative battle is held as a separate event, and it is integrated into other school activities: parent meetings, practice dives, subject weeks, etc. Creative battle is a very effective and motivational activity for expanding the boundaries of the knowledge by the pupils [13].

10. Examples of solving Open Problems.

Every year in our school there are school Olympiads on TRIZ and Eidetika (with valuable prizes), in which all grades participate. One year at the Olympiad, we purposefully gave tasks that included the solution of our school problems. Because the most exciting tasks are those that arose in the place and time where you are now. Moreover, the most memorable tasks are those in which you took direct part - the cases from your life.

For each question, each of the pupil offered several solutions. There was a rational approach and irrational fantasies, a systemic view and a chaotic sprinkling of ideas, a fervent humor and harsh irony. I will share the brightest proposals for solving school problems.

What can we do to prevent the photos of the School Leaders from being turned into «friendly cartoons» by anonymous artists?

In addition to standard solutions - to cover with a means that cannot be drawn – to use electronic means of demonstration, for example, in the photo frame all photos of schoolchildren are shown, and the leader's photos are shown longer and accompanied by some effect; a proposal to put photos of the leaders in balloons; to place photos on the ceiling (at the same time will be an exercise for the neck). However, the most original proposal was to arrange an event where everyone would paint himself or herself, take photos and post them on the «School Leaders» stand.

11. Results.

In the senior classes, due to the structuring and systematization of FSA , students are deeply versed in the content, causes and effects, and creatively memorize the material. And that is why they pass the exams to the university at a high level. Graduates say that the most important thing is that they learned at school to learn and to learn with pleasure.

Students of our school annually take part in All-Ukrainian student subject Olympiads, where they regularly take prizes in Ukrainian, English, Mathematics and Science.

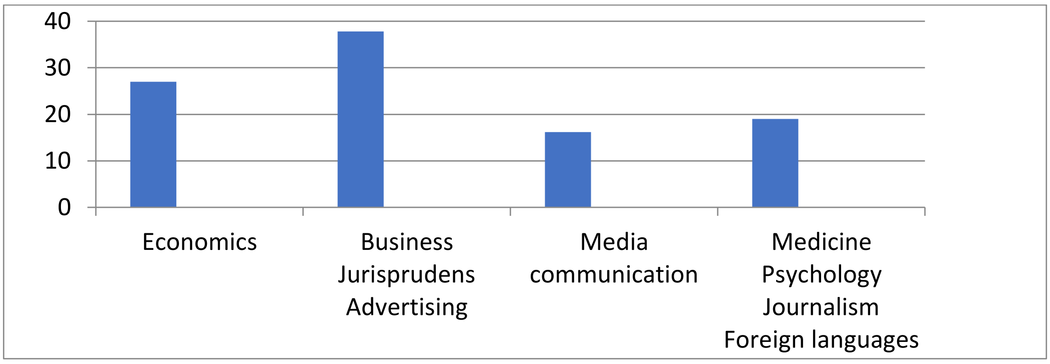
In addition, our students take part in international competitions every year, as well as participate in the international program of future leaders «FLEX». Where they always take prizes. Also, our children traditionally participate in international online Olympiads in English, Mathematics, History, as well as in the online Olympics on TRIZ and Eidetic.

Results of VNO (External Independent Evaluation): students of our school took first place in Zaporozhye according to the results of VNO of the English language (192 out of 200). Also, the students of our School took first place in the Ukrainian language (188.5) and mathematics (196) in Zaporozhye, and entered the top five according to the results of the VNO of all other subjects.

In this academic year the School confirmed the State Certification, as a result, a high level of management and the psychologization of the educational process was noted, that is, the introduction of those means in which our pupils acquire knowledge systemically and creatively.

We are interested in the achievements of everyone, and graduates constantly inform us about their lives and very often they come to the School to consult, share their successes, as well as to the New Year's KVN and holidays that everyone loves.

Our graduates have 100% admission to universities. From 50 to 70% of our graduates, depending on the year of graduation, enroll on the budget.



The diagram shows what a degree our graduates enter universities.

12. Recall of our graduates.

1. «The tools that were given to us at school deserve special words. Those methods and approaches that many of us seemed at school were not standard and distracting from, as we thought then, the main thing - the acquisition of academic knowledge; today help us out in a variety of situations. The school has taught to seek, receive and analyze information in the shortest possible time, assess prospects, seek and find non-standard approaches to solving the problem, to obtain new knowledge. Moreover, «EidoS» School was able to form a certain type of thinking in the graduates, recognizable, unique and most important «working». B.Kootz

2. «What did my school give me?
TRIZ - high productivity and efficiency in solving life and learning problems; for a short period of time to process information, and thus find time for many interesting things; Eidetic - the ability to remember large amounts of information in a short period of time; the lessons of psychology gave the ability to hear, see and feel the interlocutor and be able to cooperate with him; on psychological training was the course of «LEADERS'», where we were taught to take responsibility for our lives, our actions. In any situation, be «here and now». Ability to lead, to form a team of like-minded people and your own society.
With such skills, I enrolled to university and- from the first year until the end of my studies, I have a nominal mayor's scholarship for personal study and active participation in the public life of the faculty and university (which is a precedent for a freshman)». A.Leibovich.

13. Conclusions

1. The study and application of the model structure of FSA in education (starting from the preschool) is simply a necessity at the present stage of society development, since it is an effective way of shaping the future's system thinking, understanding cause and effect relationships, increasing awareness, increasing effectiveness and efficiency of thought activity.

2. The author's model structure of FSA is designed for use in the teaching and educational process and improving the effectiveness of pedagogical activity. The model structure of FSA is not only an instrument of didactics, but also the basis for the formation of a systemic worldview, creative thinking and intellect.

3. Use of FSA model structure by both teachers and psychologists will help to solve educational, developmental and instructional tasks, namely the following:

- Scrutinising objects from different points of view, revealing contradictions: expanding horizons, teaching tolerance.
- Developing a conceptual (purposeful) part of the emotional sphere: understanding of emotions and their enrichment.
- Enriching pupils' vocabulary.
- Developing conceptual memory.
- Building skills to analyses the development of an object and to modify its functions and properties at different levels (macro and micro).
- Developing pupils' creative imaginations.
- Developing the perception of objects of the surrounding world through all five senses: visual, auditory, gustatory, olfactory, and tactile.
- Developing system-based cogitation.
- Developing divergent thinking.
- Developing an appropriate level of self-esteem and confidence in pupils.

4. The functional system-based approach can act as a bridge taking us from the period where education is meandering and lagging behind to an educational period ahead of its time (projected) education (as defined by Marat Gafitulin) [14]). FSA provides both teachers and school students with effective tools for working with any information.

5. Experience shows that school students who have mastered the model structure of FSA demonstrate an increased level of knowledge, the existence of a research method of interaction with the outside world, they are easily adapted to changing conditions of educational and practical activities, since they know the algorithm of how to work on the task.

6. In addition, the author's model structure of FSA assists teachers in the organization of pedagogical activity: it helps to plan and organize the educational process correctly, to create own pedagogical techniques and methods.

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