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THE 12TH INTERNATIONAL CONFERENCE

TRIZ*fest*-2016

TRIZ AND QUALITY IN DESIGN AND MANUFACTURING

July 28-30, 2016, Beijing, People's Republic of China

CONFERENCE PROCEEDINGS

Editor: Valeri Souchkov

Local Organizer:

中国质量协会
CHINA ASSOCIATION FOR QUALITY

Proceedings of the 12th MATRIZ TRIZ*fest*-2016 International Conference

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The collection of papers «Proceedings of the 12th MATRIZ TRIZ*fest* 2016 International Conference» is intended for TRIZ specialists and users: academics, engineers, inventors, innovation professionals, and teachers.

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 Friends,

The time for TRIZ*fest* has come and the fact that it is taking place in China is not incidental.

Last year TRIZ*fest* was conducted in South Korea and that had been expected: for the last 10 years South Korea was a "TRIZ country number 1" with multiple TRIZ programs at Samsung, Hyundai Motor, POSCO, LG, etc. A new wave of TRIZ penetration to SME is surging there now.

However, if we look at the dynamics of TRIZ deployment and not just absolute numbers, the leadership prize goes to China. It is not the only case with TRIZ, but also with patenting dynamics – in China it is the highest in the world. The connection of these two criteria is understandable and symptomatic of the country focusing on innovation.

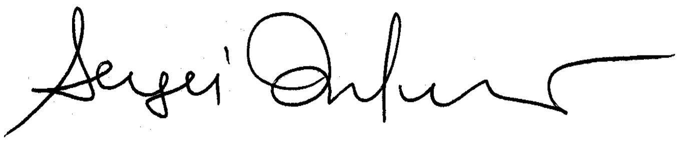
The MATRIZ conference of 2016 is very special: 2016 is an anniversary year of TRIZ founder G. Altshuller as well as TRIZ itself. Looking back we can be proud of where we are now, of the results that MATRIZ has achieved developing and deploying TRIZ.

The time period of 2015-2016 is indicative of continuous TRIZ proliferation in Asia – India, Malaysia, Thailand, Vietnam, Indonesia as well as of an influx of TRIZ activities in Europe – Germany, Austria, Poland, Italy.

Besides traditional for TRIZ areas – engineering and R&D, TRIZ is confidently moving into business, IT, entrepreneurship. "Innovative Entrepreneurs" is a key word within innovation strategies of many European, American and Asian countries.

I am confident that TRIZ*fest* 2016 will be productive and creative, writing another memorable page into the history of MATRIZ!

Sergei Ikovenko
TRIZ Master
MATRIZ President



Dear TRIZ*fest* 2016 participants,

It is the 1st time that the world most influential TRIZ conference held in China, especially, this year is TRIZ 60 anniversary and its founder, Genrich Altshuller's 90 years birthday, which made TRIZ*fest* 2016 more historical.

In the past 10 years, TRIZ made significant progress in China, no matter research, training or applications. Many companies are gaining benefits from TRIZ.

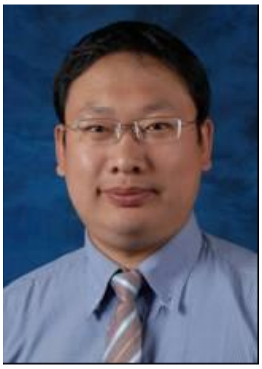
As a promoter in NICE (National Institute of Clean-and-Low-Carbon Energy), Shenhua Group, an industrial organization, I practically felt the power of TRIZ in problem analysis, problem solving and patents generation, etc. With more and more project problems were solved with TRIZ, we got a lot of solid results, the engineers learned special and better skills that the other organizations don't have, and therefore, NICE gained stronger competencies in technology innovation. An engineering culture of TRIZ is being formed in NICE.

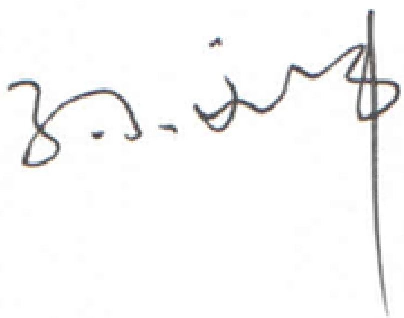
TRIZ*fest* 2016 will be held in Beijing, and it will be a big move for TRIZ, since TRIZ is entering the most active economic entity of the world. For China, this event will open a new world, since more Chinese TRIZ experts will have chances to see what is happening all over the world. This will make China TRIZ grow even faster.

To prepare this international event is not easy. The organization committee from MATRIZ and CAQ has done a lot of work. We are happy to see that these two influential organizations made perfect cooperation and really made this event happen. We are appreciated the work by the committee members.

We hope you enjoy this conference, sharing experiences, making friends… Have a good stay in Beijing.

Yongwei Sun
Manager and Master Black Belt of Quality Management Department, NICE
MATRIZ Level 4 and Member of MATRIZ Presidium
Expert Member of China Council for Promoting Six Sigma, CAQ





Dear TRIZ*fest* 2016 Participants,

Welcome to Beijing! It is a pleasure to announce the proceedings of the 12th International Conference "TRIZ*fest* 2016" which will be conducted on July 28-30, 2016 in Beijing, People's Republic of China.

It is the second consecutive year when the conference of The International TRIZ Association, MATRIZ is conducted in Asia, and specifically in China, a country which recently became the world largest and influential technology center, and which has been extremely active with adapting, developing and implementing new methods and tools to enhance productivity, quality and innovation.

It took some efforts to prepare this conference since The Organizing Committee received 96 paper abstracts written by 137 authors and co-authors from 16 countries. The Paper Review Board worked hard to select best papers to be presented at the conference.

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

We would like to thank all the authors and co-authors who presented their works in these proceedings and therefore provided considerable contribution to the development of TRIZ and its further dissemination around the world.

We would like to express our sincere gratitude to all the members of the TRIZ*fest* 2016 Organizing Committee who provided their help and support as well as members of the Paper Review Committee who invested their time to prepare the conference.

And at last but not least, we would like to express thanks to China Organization for Quality which made the conference possible.

Valeri Souchkov
TRIZ Master
Co-chair of the TRIZ*fest* 2016 Papers Committee
Vice President, The International TRIZ Association
Enschede, The Netherlands

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A KNOWLEDGE INSPIRED TRIMMING METHOD BASED ON TRIZ

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Abstract

Trimming is one method of reorganizing system functions with partial existing resources, thus greatly enhancing the system level of idealization. The critical point for trimming process is that resources mining and transformation in the system and super-system, in which aspect conventional trimming methods have some limitations. In order to effectively inspire designers to mine and transform resources, the inventive principles in TRIZ are taken as inspired knowledge during the trimming process. Based on the mapping between functions and attributes, and similarity analysis of attributes and engineering parameters, build the mapping relationship between the function and the invention principle; Meanwhile, based on the inventive principles and the different types of resources needed in getting the solution, construct the mapping relations between the inventive principles and the different types of resources. On this basis, a knowledge inspired innovative design process model of trimming is proposed and verified effectively in the innovative design of armoring machine.

Keywords：*trimming, inventive principles, resources, knowledge inspired*

1. Introduction

Trimming is an analysis and solving tool in TRIZ, which solves problem by removing components and reallocated useful functions with existing resources of the system and super-system [1]. The trimming method has two steps. The first is determining which components in the system should be trimmed; the second, which is also the key part, is mining the useful resources in the system and super-system to reallocation the useful functions of the system[2-5]. The components to be trimmed are usually determined by some evaluation methods，such as value analysis, cost analysis, et al. Useful functions reallocation is essentially a process of mining and transforming resources in system and super-system [6-7]. In the conventional method, this process is mainly guided by some guiding rules [8-10]. YEOH proposed three guiding rules based on relationship between components to search for resources available for functions allocation [9]. SHEU extend the rules and construct a systematic trimming process model [6]. D.L. Mann proposes a series of heuristic questions to inspire designer find resources available for functions reallocation, which based on function capturing, system completeness, functional requirements and DFMA [10]. RAWATSCH propose some heuristic questions base on technical evolution analysis to inspire designer [11]. How effective these guiding rules and heuristic questions above are actually depended depends on the designer. The designers are often unable to find available resources for functions allocation due to thinking inertia and knowledge limitations [2].

Inventive principles are some problem solving measures which derived from analysis and summary of numerous patents [12], which transform and utilize resources to solve problem. So, it can be used as a kind of objective knowledge to mining available resources in the system and super system for functions allocation. On this basis, a type of knowledge-based trimming method is proposed, which inspire the designer with the objective knowledge to reallocate useful functions.

2. Determination of Trimming Inspired Knowledge

Resources in the technical system can be divided into directly available resources and derived resources. Designer can easily found and use the directly available resources. So the real challenge for designer is mining the derived resources [13-15]. Inventive principles assist designers to mining and transforming the derived resources inside and outside the system. So, it can be used as the inspired knowledge to derive resources for functions reallocation when the components be trimmed. There are numerous principles and there are a number of specific measures of each principle. Therefore, for such a large number of inspired knowledge，it is necessary to build a retrieval method to get the required knowledge quickly and efficiently

2.1 Function Based Classification of Inspired Knowledge

(1). Relationship between functions and attributes

Huang and Zhang [16-18] pointed out that attributes are characteristics of a system or a component and function can be regarded as maintaining or changing the attribute(s) of the system. When the system get or lose some functions, the attribute values will change or hold. There are a total of 59 attributes summarized by existing literature [17]. Integrating 37 functions from function database of Creax and several from Innovation Suit, there are total of 43 functions [19]. Based on the attributes list we can get the mapping relations between functions and attributes, shown in Table 1.

Table1

Mapping relations between functions and attributes

function	attributes
Accumulate	mass、weight、volume、position、shape、surface finish、density、homogeneity
deposit	mass、weight、volume、position、shape、surface finish、density、homogeneity、wholeness、phase state
…	…

Source: Identification of Relevant Technical Trends based on Function-Attribute Relationships

(2). Relationship between functions and 39 engineering parameters

Some of the attributes in Table 1 are derived by some other attributes. For example, mass is the product of density and volume. So, we can consider that mass is derived from volume and density. On this basis, the mapping relations between functions and engineering parameters can be constructed [16-17].

Table 2

Mapping relations between functions and engineering Parameters

function	Engineering Parameters
accumulate	weight of moving object/stationary object、power、volume of moving object/ stationary object、shape

deposit	weight of moving object/stationary object、power、volume of moving object/ stationary object、shape
…	…

Source: Identification of Relevant Technical Trends based on Function-Attribute Relationships

(3). Construction of the mapping relations between functions and inventive principles

When some parameters need to be improved in a system, Matrix 2010 gives some recommended inventive principles to solve the problem [20], which as shown in Table 3.

Table3

Mapping relations between improved parameters and inventive principles

Improved parameters	Optimized principles	Improved parameters	Optimized principles
1 weight of moving object	31、35、40	3 length of moving object	4、14、15、17
……	……	……	……
49 ability to measure	2、24、26、28、32	50 measure precision	3、4、24、32、37

Source: Matrix 2010

From the above, we can construct the mapping relations between functions and inventive principles by combining Table 1 to Table 3, as shown in Table 4.

Table4

Mapping relations between functions and inventive principles

functions	Optimized inventive principles
accumulate	1、3、4、7、17、19、30、31、35、40
absorb	1、3、4、7、17、19、30、31、35、40
corrode	1、3、4、7、10、11、12、14、24、30、31、32、34、35、39
stabilize	1、3、4、5、7、9、10、11、12、14、15、16、17、19、21、22、24、25、28、30、31、32、35、36、37、39、40
extract	2、12、13、17
changes phase	1、3、7、12、19、24、30、31、32、35、36、40
join	1、7、30、31、35、40
mix	1、7、30、31、35、40
clean	3、16、31、35、40
erode	1、3、4、5、7、10、11、14、15、17、19、24、28、31、32、35、39、40
embed	1、5、28、29、31、35、40
remove	1、3、7、30、31、35、40
condense	1、3、7、19、30、31、35、40 、(36)
detect	5、28、35
evaporate	2、36 、（1、3、7、30、31、32、35、36、40）
produce	3、31、35
bend	1、3、4、5、10、14、15、17、28、29、35
cool	1、3、4、7、14、15、17、30、31、32、35、36、40
protect	3、11、12、21、22、24、34、35、39
dry	3、19、31、35、40
freeze	1、3、7、30、31、32、35、36
deposit	1、3、4、7、17、19、30、31、35、40
decompose	1、3、4、7、11、12、17、19、28、30、31、34、35、40
vibrate	2、3、5、9、10、12、19、24、26、28、32、34、35、36

preserve	1、3、4、7、10、11、12、14、15、17、19、21、22、24、30、31、32、34、35、36、39、40
lift	12、13、17
separate	1、2、11、15、25、28、27、29、35
prevent	3、12、21、22、34、35、39
locate	17、23、32
destroy	3、5、9、10、12、19、21、22、28、35、39
break down	3、5、10、12、19、28、34、35、40
hold	3、4、7、10、16、17、23、24、25、32、37
break down	2、9、11、12、28、35
heat	1、3、4、7、12、14、15、17、19、24、30、31、32、35、36
move	15、18、21、29、37
orient	15、28、29、35
assemble	1、2、7、11、24、26、28、30、31、32
integrate/combine	5、6、7、33、40
rotate	15、17、19
boil	1、3、7、30、31、32、35、36

2.2. Select the Trimming Inspired Knowledge Based on the Mapping

Relationships between Resources and Principles

As already mentioned, any technique system is part of a super-system and a part of nature. It exists in space and time, consists of and/or uses substances and fields, and performs functions. Therefore, in TRIZ, resources are divided specifically into six types, which are substance, field, information, time, space and function resources [13]. In the solving process, the inventive principles are many measures of how to mining and transform resources. So there is a certain link between the resources and principles.

Semyon D. Savransky classifies the inventive principles by functional attributes of technical system and subsystems [21]. Function can be described as maintaining or changing an attribute(s). And we can easily know which types of resources are required to achieve a function in a technical system. So, the mapping relations between the attributes and the type of resources can be derived, as shown in Fig1 a-b-d. Then according to mapping relations between functional attributes and inventive principles, mapping relations between resource types and inventive principles can be derived (Fig. 1c-d-e). The specific mapping relations are shown in Table 5.

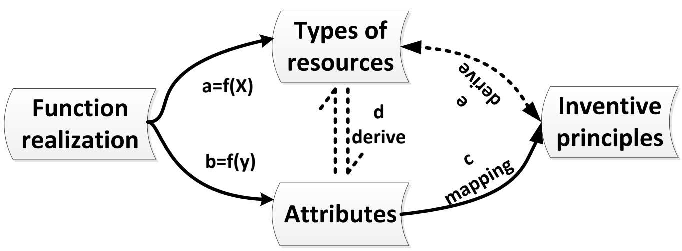

Fig.1 Construction of the mapping relations between type of resource and inventive principles

Table 5

Resource based classification of inventive principles

Types of resources	Inventive Principles
Substance resources	1,34,27,2,33,5,24,26,36,6,3,38,39,40,31,29
Field resources	13,22,10,9,11,8,15,16,18,35,32,36,37
Time resources	21,19,20,18
Space resources	4,14,12,7,35
Information resources	25,23,28

2.3. Multi-level selection strategy of trimming inspired knowledge

The inventive principles provide inspired knowledge to mine the available resources in the system and super-system. However, there are a large number of principles and there are a number of specific measures of each principle. Therefore, for such a large number of inspired knowledge， it is necessary to build an efficient knowledge retrieval method to get the required knowledge quickly. Based on the mapping relations between functions and inventive principles and the mapping relations between resource and inventive principles, a multi-level selection strategy of inspired knowledge is proposed, as shown in Fig. 2.

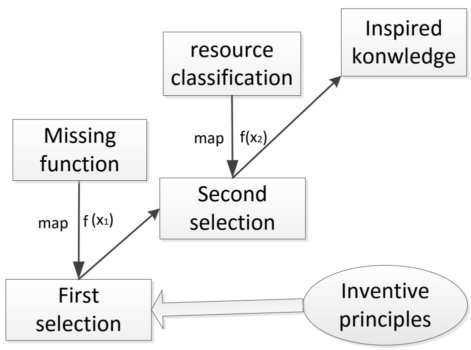

Fig.2 Multi-level selection strategy of inspired knowledge

First, when some components are trimmed, there must be some missing functions which are necessary for system. According to the functions, look-up table 4 to get some inspired knowledge. This is the first time to select; then, according to the missing functions, determine the types of resource involved to achieve the function. Look-up table 5 to get inspired knowledge. This is the second time to select; those knowledge both emerged in the two selection process, will be the preferred knowledge we can choose.

3. Knowledge Inspired Innovative Design Process Model for Trimming

The process model is shown in figure 3. Specific steps are as follows：

(1). Select the target system. It can be an existing product or just a conceptual design scheme;

(2). Build the system functional model, which is the basis of trimming method.

(3). According to the design target, choose root cause analysis, cost analysis or harmful analysis to determine the components to be trimmed. Then trim them and get the trimming model.

(4). According to the trimming model, we can determine the system's missing function. look-up table 4 to get the inspired knowledge.

(5). Then, according to the missing functions, determine the involved types of resource. Look-up table 5 to get inspired knowledge. Those both emerged in the two selection process, are the preferred inspired knowledge.

(6). According the preferred knowledge, the designer mines available resources in the system or super-system for the function reallocation. If successful, the solution is obtained. Then go to the next step; if not, go back to the third step.

(7). If the solution meets the target, it will be the final solution; if not, go back to the third step if there is any components to trim.

4. Case study

Cable industry is the second industry in China [22]. In some cases, cables need to be equipped with armor layer with steel strip, which is carried out by armoring machine, as shown in figure 4. Steel strip plate rotates with the shaft of steel strip plate. The shaft of steel strip plate through mounted on the roller of spindle. However, the weights of steel strip shaft are not balanced on both sides of the roller of spindle. The unbalanced centrifugal inertia force produced by the rotation produces additional dynamic pressure, especially when the speed of spindle is fast. The dynamic pressure affects the strength of the machine, reduces the production efficiency, and leads to machine vibration and noise [23].

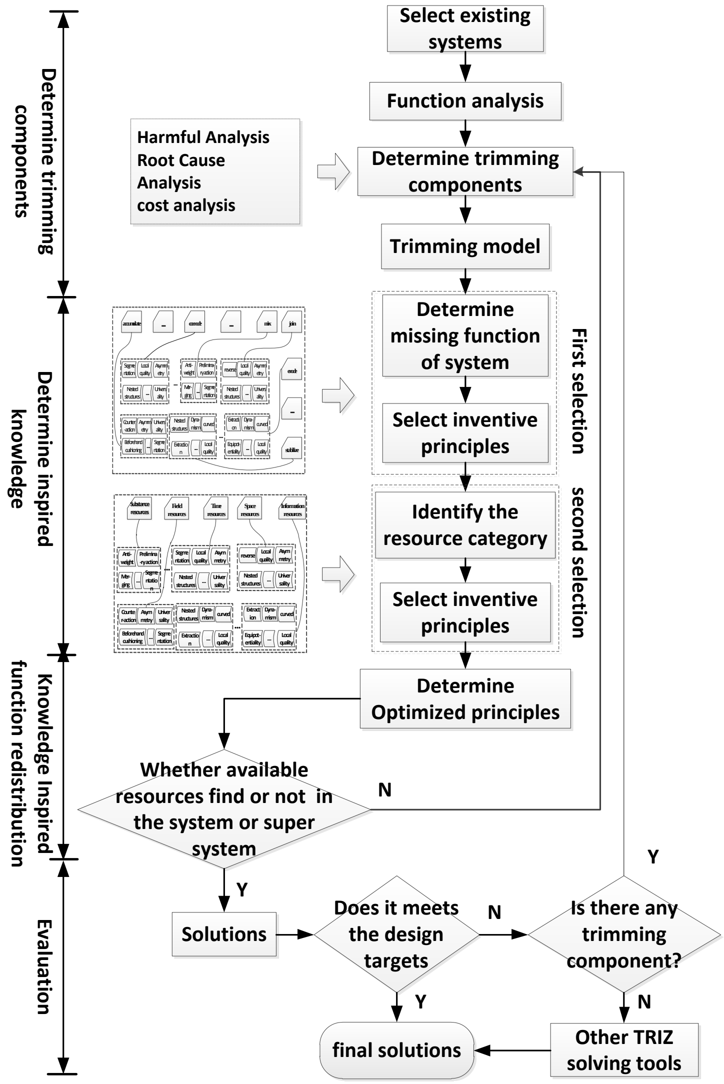

Fig.3 The process model of knowledge inspired trimming method

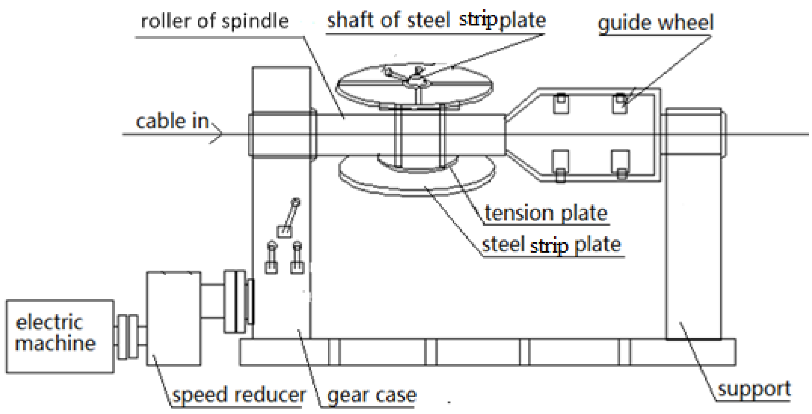

Fig.4 The structure diagram of current armoring machine

4.1. Determination of the components to be trimmed

According to the root cause analysis, the weights of steel strip shaft are not balanced on both sides of the roller of spindle that leads to machine vibration and reduces production efficiency. On this basis, build the functional model of armouring machine, as shown in figure 5. According to the results of root cause analysis, determining the trimming components are shaft of steel strip plate and steel strip plate.

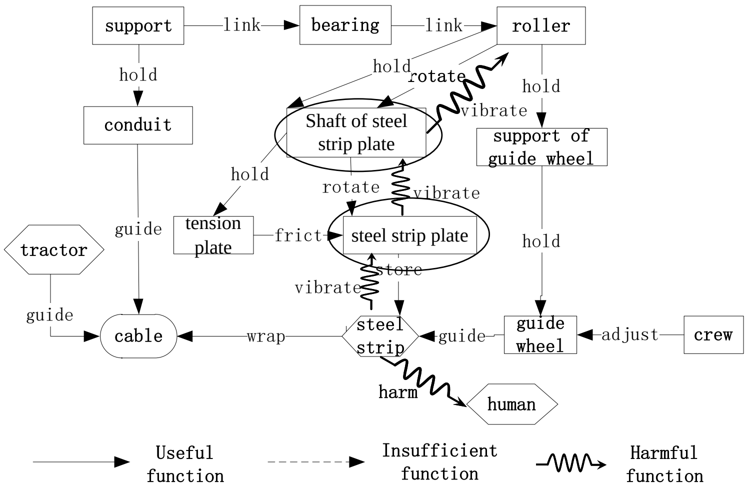

Fig.5 The functional model of Armoring machine

4.2. Determining the inspired knowledge of trimming

(1). The useful functions of "rotation" and "hold" to the roller and tension plate are missing after trimming the shaft of steel strip plate. look-up table 4 and get those inventive principles, “hold”: 3、4、7、10、16、17、23、24、25、32、37; “rotate”: 15、17、19.

(2). The steel strip plate cannot rotate after trimming the shaft of it. So it apparently needs energy resources to provide power. As shown in fig.5, the roller, which originally hold and rotated the shaft of steel strip plate maybe can provide the energy and function. But, how? How and where the steel strip plate and tension plate are hold obviously relating to the space resource. According to analysis, there is no directly available resources in the system. So, look-up table 5 and get those inventive principles related to space resources: 4、14、12、7.

According to the intersection of the two selections results, the optimal inspired knowledge of trimming are the inventive principles of No.7 “nesting” and No.4 “asymmetry”.

4.3. Solution

According to the inventive principle of No.7 "nesting", nested the steel strip plate to the roller of the armoring machine. The improved system is shown in fig.6, and the schematic diagram is shown in fig. 7.

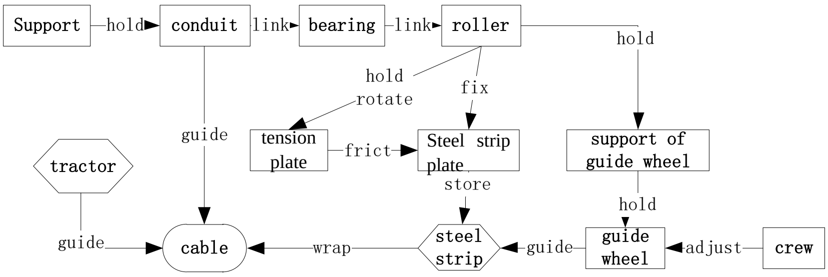

Fig.6 The functional model of improved armoring machine

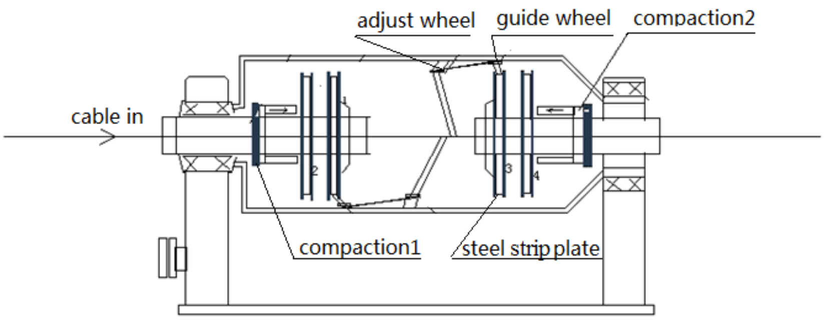

Fig.7 The schematic diagram of the improved armoring machine

4.4. The evaluation of the solution

(1).The shaft of steel strip plate disappears in the improved armoring machine and there is no new component added. So, the structure is simplified.

(2). Centrifugal force is the product of the distance between mass center and shaft center, the square of the angular velocity and mass, which is presented as $F=m\omega^2r$. The steel strip plate through mounted on the roller in the improved armoring machine, so the distance between center of mass and center of axis is zero. As a result, the centrifugal force which is the source of harmful effects of vibration and noise disappear, then the stability and the production efficiency are improved.

(3).For the improved armoring machine, it is workable in principle. The 3D simulation model of the improved armoring machine is shown in fig.8. Existing mechanical processing technology provides technical support for the scheme and it has been accredited by engineers in a cables enterprise.

In conclusion, the improved design eliminates severe vibration and noise, effectively improves the safe operation speed and the production efficiency.

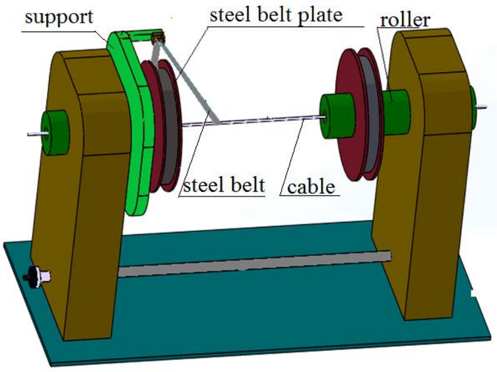

Fig.8 The 3D simulation model of improved armoring machine

5. Conclusion

On the basis of the existing trimming methods, this paper introduced the inventive principles as the inspired knowledge of mining the available resources in the system or super-system, having making up the limitation of lacking objective knowledge inspiration in the process of system useful function assignment in the existing trimming. Starting with missing function in trimming model, construct the mapping relationship between the function and the invention principle and the mapping relationship between the resource type and the invention principle. On the basis of this, a fast and effective heuristic knowledge selection method of trimming is established. And construct the innovative design process model of trimming. The innovation design of armoring machine shows this method can effectively support the trimming innovative design process, which is conducive to the effective and rapid product innovation.

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A SYSTEM OF STANDARD INVENTIVE SOLUTION PATTERNS FOR BUSINESS AND MANAGEMENT PROBLEMS

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Abstract

In Classical TRIZ, Substance-Field Analysis and a System of Standard Inventive Solutions has been regarded as two complimentary tools to solve a majority of inventive problems emerging in the areas of technology and engineering. The paper addresses the question: can the same or a similar approach be used to deal with problems and challenges emerging in the areas of business and management?

In addition to introducing a problem modelling framework similar to Substance-Field modeling, a new categorization of types of inventive problems and a new system of Standard Inventive Solution Patterns for Business and Management (ISBM) are proposed. The approach is illustrated by a number of new definitions of Inventive Standards for business and management.

Keywords: TRIZ, Standard Inventive Solutions, Inventive Standards, TRIZ for business and management.

1. Adaptation to Business and Management

1.1. A Classical Approach

As follows from the studies performed to identify which TRIZ technique is used most often, it was found that the most popular technique are a combination of the contradiction approach with 40 Inventive Principles and Contradiction Matrix [1]. However, it is not well known that both 40 Inventive Principles and Contradiction Matrix were abandoned from the use in TRIZ by their author G. Altshuller who, after many years of developing TRIZ, came to the conclusion that the Contradiction Matrix and Inventive Principles provide rather low effectiveness due to the high degree of trials and errors [2].

During development one of the major TRIZ techniques -- ARIZ, it was revealed that the vast majority of inventive problems occur due to an undesired effect which appears as a result of physical interaction between two components or several groups of components. in ARIZ, such components are known as a "tool": a component which is a carrier of a function (producing action), and a "product": a component whose attribute or a group of attributes experiences change as a result of the action produced by the tool. A combination of a "product" and a "tool" is known as a "conflicting pair" in ARIZ [3]. Further development of ARIZ helped to extract, generalize and describe a number of typical physical interactions between a product and a tool as well as effects emerging from such interactions and match them with a number of typical solution patterns. Such solution patterns specify how a certain problem can be solved by modifying a system that includes the conflicting pair. Such typical patterns of solutions were collected to a system which is known as a "System of Inventive Standards" [4]. As a matter of fact, the collection of Inventive Standards was developed to replace the Contradiction Matrix and 40 Inventive Principles. Inventive Standards are more formal than Inventive Principles since they operate with specific models of systems and problems. Inventive Standards are more accurate than Inventive Principles and narrow down search field towards a solution space which includes most ideal solution models.

The term "Inventive Standard" means that there is a common, or a "standard" method to solve a group of different inventive problems that have the same problem model. To solve a problem with Inventive Standards, there is no need to explicitly formulate a contradiction, which still presents but remains hidden in the problem formulation.

To model different technical problems in uniform way, so-called "Substance-Field Modelling" approach is used. The basic concept is that any part of a technical system where a problem emerges can be presented as a system of interacting substance components and the problem is exposed as undesirable change of either a substance component or an interaction. Interactions between substance components are presented by so-called "technical fields" or physical forces. The role of fields and forces is to carry a function produced by one of the modelled components. Examples of such technical fields are mechanical, acoustic, thermal, electric, magnetic, electromagnetic, etc.

A problem model is defined in terms of a substance-field ("su-field") which consists of at least two substance objects and a field/force between them, which provides interaction responsible for the problem. An object might be an aggregated group of objects as well. For instance, su-fields presenting a model of a system and a model of a problem of ineffective cutting of frozen butter (object 1) by a knife (object 2) are shown in Fig. 1. The dashed line indicates a problem: cutting is delivered ineffectively. Both the substance components interact with each other via mechanical field.

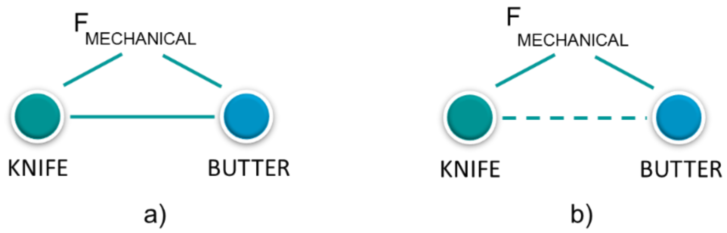


Fig. 1. Substance-field models of a) a system for cutting bread with a knife and b) of a problem of ineffective cutting of butter by a knife. A dashed line indicates that the function of cutting is delivered ineffectively.

An Inventive Standard consists of two parts. The left part specifies a generic model of a problem and might include some critical restrictions. The right part shows a model of a solution. For example, one of the Inventive Standard which can be applied to the problem model presented above includes the following recommendation: "*If it is necessary to improve efficiency of su-field, and replacement of su-field components is not allowed, the problem can be solved by the synthesis of a dual su-field by introducing a second field between the substance components which is easy to control.*" (Fig. 2)

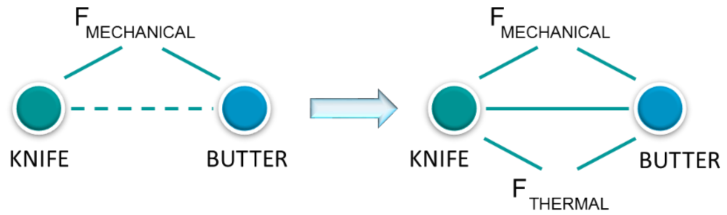


Fig. 2. Solving a problem of cutting frozen butter by applying an Inventive Standard "Transition to dual Su-Field". A solution is that the knife produces heat during cutting which melts butter.

In the past decade, TRIZ has become recognized as the best practice of the innovation front-end at a number of world-leading companies. While the vast majority of TRIZ applications cover technology and engineering, the fundamental concepts of TRIZ approach to problem analysis and creative ideas generation are based on several fundamental concepts which can be used within a broader context than technological and engineering only.

Among such areas where innovative problems emerge and which cause large interest are business and management. One of the authors has been exploring applicability of TRIZ to business and management since 1998 [5], including application of the System of Inventive Standards, and the results seem to be rather encouraging.

The phenomenon of successful applications of TRIZ and its tools in non-technical domains (e.g. [6]) can be explained by the fact that TRIZ focuses on studying high-level patterns and regularities of non-linear (in other words, inventive) evolution of technical systems. However, these systems are a subset of a broader class of artificial, man-made systems. Since the TRIZ paradigm was successfully confirmed across many engineering domains from mechanics to microelectronics, a key assumption can be made that general mechanisms of systems formation and evolution are similar and do not depend much on a domain. Thinking patterns which we use during a phase of creative problem solving process, deal with changing systems, would it be a car, or a building, or a pizza shop. Therefore another assumption is that once we need to solve a problem in the knowledge area which is based on evolution of systems, such as business systems, or social systems, we tend to apply the same abstract patterns as in case of technical systems.

For example, imagine a system (in any domain) which consists of two objects: 1 and 2. Objects 1 and 2 interact with each other, and the result of this interaction is that object 1 negatively affects object 2. There is a set of abstract solution patterns to prevent this problem from reoccurrence by changing a system of objects 1 and 2:

- We can shield object 1 from object 2 by introducing a new object 3 between them.
- We can remove object 1.
- We can increase the distance between object 1 and object 2.

The usability of one or another pattern depends on a specific set of constraints and demands. A more difficult case happens when we need to maintain the interaction between objects 1 and 2 since it produces a positive effect in addition to the negative effect. In this case, the solution patterns are as follows:

- We can introduce object 3 between objects 1and 2 which will filter out the negative part of interaction while letting the positive action to pass through.
- We can eliminate a property of object 1 which produces the negative effect.
- We can neutralize a property of object 1 which produces the negative action.
- We can decrease sensitivity of object 2 to be affected by the harmful effect.

- We can modify the environment of objects 1 and 2 so that the environment neutralizes the harmful effect.
- etc.

As we can see, such abstract patterns can be interpreted within and applied to virtually any type of systems: from microelectronics to social systems even if these domains incorporate rather different backgrounds.

The problem with the Classical TRIZ System of Inventive Standards is that it was developed for engineering applications and therefore brings specific technical language. There have been attempts to create either universal or simplified systems of Inventive Standards through further abstraction, for example, presented in [7], [8]. However, too much abstraction leads to a contradiction: the more abstract problem solving patterns are, the more universally they can be applied but their use becomes difficult due to a large gap between the degree of generalization of such patterns and specifics of real-world problems. This contradiction can be resolved by maintaining a balance between the patterns of the high degree of abstraction and patterns of a lower degree of abstraction which can be less universal but important for a specific knowledge domain.

Another interesting approach is suggested by M. Rubin [9] who attempts to develop a universal system of standard solutions in which the problem solving patterns are structured along the lines of solutions evolution. However, while the approach is promising, several critical questions arise: for example, one of the lines of evolution is the line of software evolution which may not be treated as universal.

1.2. Object-Field Modeling Instead of Substance-Field Modeling

As mentioned above, earlier attempts to directly apply the original TRIZ techniques and knowledge bases to non-technical areas caused certain difficulties, primarily due to the specific language used in the original TRIZ texts related to technology and the lack of examples and case studies from business and management. Due to this, attempts of some TRIZ experts to transfer TRIZ to business and management by using classical TRIZ materials, which were designed for the use in technology and engineering, often failed. For example, trying to explain a substance-field analysis to a human resource manager in most cases creates confusion when the manager tries to imagine that a person is "substance". Using original definitions leads to a perception gap and difficulty with transferring TRIZ knowledge to the non-technical world.

Regarding classical TRIZ-based substance-field analysis, a problem with the word "*substance*" can be easily solved by replacing the word "substance" with the word "object" which means any material or non-material matter within specific context and borders (e.g. person, paper, car, report, conversation, salary, bonus). Even such the words as "promise" and "advice" can be considered as objects since they capture clear contents within specific borders. In addition, a process or its part can be identified as an object.

However, a larger difficulty is created by the attempt to understand what to consider as a "*field*" when modelling business and management problems in terms of substance-field (or "object-field") analysis. We must note that the definition of the term "technical field" in the TRIZ version for technology and engineering does not match definition of the term "field" in physics (for example, such fields as "thermal field" or "mechanical field" do not exists in physics), but they were introduced to improve convenience of modelling and solving technical problems.

Some TRIZ developers tend to eliminate a field from a problem model to simplify the problem solving approach by leaving only objects and a function between them in the problem model. But the use of the concept of field is essential due to the fact that it is a field which defines background of interaction. For example, when two persons have a conversation in a room, we can define several fields creating this interaction: visual, verbal, emotional, informative. But not all these fields are usually a source of a problem: it can be either visual field if one person does not like how the other person looks; or emotional field if one person's confuses another person; or informative field if one person does not receive all facts he expected to hear. As known in classical TRIZ, a more ideal solution to a problem most often can be obtained when we focus on the improvement of a specific field which causes a negative or insufficient effect. A solution has to be found while maintaining this field without replacing this field. Therefore if one person visually irritates another person, the most effective and a solution most close to ideal one can be obtained by dealing with visual field rather than verbal or informational fields (thus trying to solve a wrong problem). A model of a problem in case of a problem caused by irritation must include visual field.

To create a classification of such fields, Belski [10] proposes so-called "human fields" which are based on human perception and are organized to five classes: 1) Senses, 2) Verbal communication, 3) Non-verbal communication, 4) Real material possession, 5) Non-real material possession. While this classification is useful, other types of fields can be used, for example a field of "cohesion". In addition, fields presenting physical interactions can be used as well when modelling inventive problems. As follows from our experience, when modelling systems in object-field terms, some fields can be aggregated. For example, there is no need to separate between visual and verbal components in communication unless only one of them causes a problem. Several examples of object-field models of business systems are shown in Fig. 3. The study of types of fields which can be used to define functional interactions in business and management systems is currently under way.

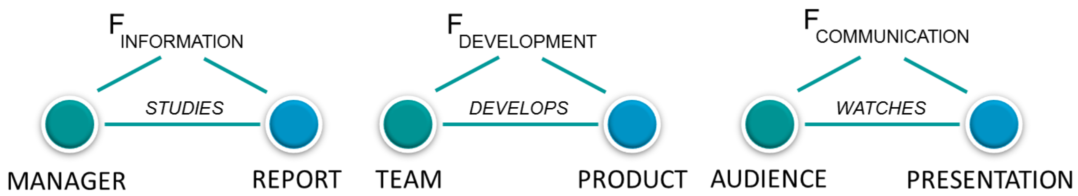


Fig. 3. Several instances of object-field models which include critical fields.

1.3. Problems and Solutions

Similar to technology, in business and management, vast majority of problems arise when a specific interaction can not affect value of a certain attribute of at least one of the objects engaged to interaction or both objects as desired, or the interaction can not prevent value from being affected. A problem emerges because it is not known how to either change value of an attribute within the constraints and demands given, or opposite, how to prevent the value of an attribute from being changed.

Since none of known solutions and problem solving methods available in a specific business domain help, a new solution which has not been known before is required. In technology, such problems are called "inventive". A major difference between technology and business is that once a problem in technology is solved, it can be patented and a solution can be called "invention". In business, however, patents are not available and business solutions are rarely called "inventions". Nevertheless, if a radically new solution in a certain business domain has been proposed, it makes sense to call such both solutions and problems "inventive".

For example, a very common case in various businesses is that sales of a product at the consumer market do not bring sufficient revenue. Such a problem can be modelled as ineffective result of interaction between two objects: a supplier and a consumer. But depending on a situation, a field in each specific case which is responsible for the interaction that creates the problem might differ: for example, it can be informative – if the supplier does not convince the consumer to buy the product; or trust – if the consumer does not trust the supplier. As clear, in both situations both problem models and solutions will be different. In the first case, the problem will be created by the interaction between a supplier who does not provide enough information to the customer, and in the second case, it will be a problem based on the field of "trust" which has nothing to do with either the lack of information or with the qualities of the product.

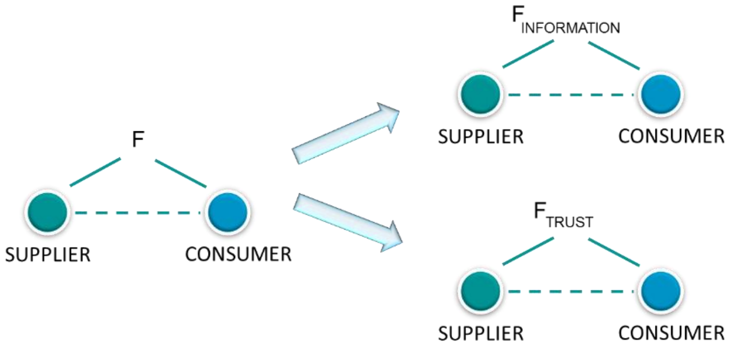


Fig. 3. Role of specific fields in modeling problems in object-field terms.

On top of that, there might be another reason why consumers do not purchase the product: because they do not feel happy about owning this particular product due to its design. In this case, the field will be emotional, and the interaction will be between the product and the consumer, while the field will be emotional: the product does not produce sufficient emotional impact on the consumer.

In summary, understanding what "field" is responsible for creating a problem helps to narrow down the scope of future solutions towards most ideal solutions space by focusing exactly on dealing with that particular field.

1.4. Modelling Problems

In both substance-field and object-field models presented graphically, problems are specified by defining a specific problem-creating type of interaction. There are five general types of interactions which identify problems, as shown in Table 1.

Table 1

Types of interactions specifying problems in object-field models

Type of interaction	Graphic notation used	Examples
Insufficient (ineffective) result of interaction		1) The project is not delivered in time. 2) Revenues from selling a product are insufficient. 3) Advertisement does not produce sufficient conversion rate.
Excessive (non-optimal) result of interaction		1) Too much budget is spent for advertising. 2) Too many visitors overload reception workers.

Poorly controlled result of interaction		1) A manager poorly controls a business process. 2) Deliveries by a supplier can not be properly controlled.
Harmful (negative) result of interaction		1) An office worker irritates other people in the office. 2) Loud packaging process disturbs employees in a room.
Non-informative or incorrect result of measuring effect of action or interaction		1) Results of audit are inaccurate. 2) A company produces wrong forecasts. 3) Information about results of partner's activity is missing.

It is often a case, when insufficient, excessive or poorly controlled results of actions or interactions are misinterpreted as harmful. It is important to identify harmful interaction by the following rule: a harmful (negative) interaction is such interaction which does not produce any positive effect but which results in the negative effect that is absolutely not desired. For example, if the supplies are not delivered in time, it can be either insufficient or poorly controlled result of interaction since the final result – delivery – is a positive effect but not delivered as expected. However, in case if a product is broken during delivery we deal with a harmful effect of interaction since there is no desire to have a product to be broken at all.

2. A New System of Inventive Standards for Business and Management

2.1. Structure and Organization

The classical System of 76 Inventive Standards was organized and structured by G. Altshuller on the basis of evolution of technical systems: from a non-existing technical system to the point when a technical system experiences transition to a microlevel of integrates to a supersystem. The system is divided to classes to separate Inventive Standards for change from Inventive Standards for measurement. The system of Inventive Standards for business and management is organized in a slightly different way: there are no classes, but there are groups according to a category of problems. Each Inventive Standard has a number where the first number stands for the group (category of problem), and the second one locates place of the Inventive Standard in the group. A current version of the system is based on combination of a study of over 1200 different business cases.

Similar to the classical system of 76 Inventive Standards, where the same substance-field models of solutions can be used for the problems of change and measurement/detection, in the system of Inventive Standards for Business and Management (ISBM), the same object-field solution models can be used for different type of problems.

Currently all Inventive Standards for business and management are organized to five groups:

- Group 1: Improving insufficient effect of an interaction.
- Group 2: Improving excessive effect of an interaction.
- Group 3: Improving poorly controllable effect of an interaction.
- Group 4: Eliminating negative effect of an interaction.
- Group 5: Organizing or improving measurement and detection.

In each group, inventive standards are ordered according to the degree of system change, which is required to solve a problem. Inventive Standards which do not require large change are located in the top of the list and Inventive Standards which require a large-scale change are located at the end of the list.

It is important to note that only those solution patterns are included to each group which are most often used to solve this particular category of problems.

Currently the ISBM system [11] includes 39 inventive standards (fig. 4). As said above, some of the inventive standards in different groups have identical solution models while the problem models are different.

- Group 1: Improving insufficient effect of an interaction
    - Standard 1-1: Transition to internal complex model
    - Standard 1-2: Transition to external complex model
    - Standard 1-3: Introducing intermediary
    - Standard 1-4: Using existing resource
    - Standard 1-5: Using modified or new environment
    - Standard 1-6: Transition to dual model
    - Standard 1-7: Transition to periodic action
    - Standard 1-8: Introducing selective protection
    - Standard 1-9: Introducing selective amplification
    - Standard 1-10: Segmentation of objects and processes
    - Standard 1-11: Dynamization of objects and processes
    - Standard 1-12: Transition to bi- and poly-systems, networks
    - Standard 1-13: Increasing differences in bi- and poly-systems
    - Standard 1-14: Increasing depth of nesting
    - Standard 1-15: Paradigm change
- Group 2: Improving excessive effect of an interaction
    - Standard 2-1: Introducing filtering
    - Standard 2-2: Modified environment
    - Standard 2-3: Removing excess of action
- Group 3: Improving poorly controllable effect of an interaction
    - Standard 3-1: Introducing intermediary
    - Standard 3-2: Transition to external complex model
    - Standard 3-3: Replacing paradigm
    - Standard 3-4: Outsourcing to supersystem
    - Standard 3-5: Transition to chain model
- Group 4: Eliminating negative effect of an interaction
    - Standard 4-1: Introducing intermediary
    - Standard 4-2: Introducing modified intermediary
    - Standard 4-3: Distraction by a new field
    - Standard 4-4: Introducing antipodal action
    - Standard 4-5: Introducing conditions
    - Standard 4-6: Modified object in advance
    - Standard 4-7: Periodic action
    - Standard 4-8: High speed
    - Standard 4-9: Paradigm change
- Group 5: Organizing or improving measurement and detection
    - Standard 5-1: Problem change
    - Standard 5-2: Using a copy
    - Standard 5-3: Successive detection
    - Standard 5-4: Indirect resource measurement
    - Standard 5-5: Transition to a dual model
    - Standard 5-6: Transition to bi- and poly-systems
    - Standard 5-7: Measuring derivative

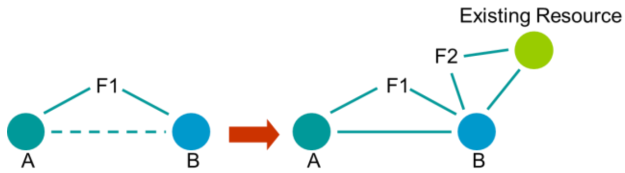
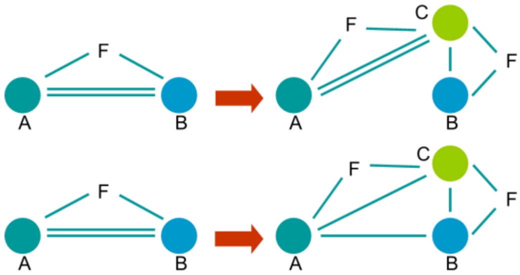
Fig. 4. Contents of current version of the System of Inventive Standards for Business and Management.

2.2. Examples of Inventive Standards for business and management

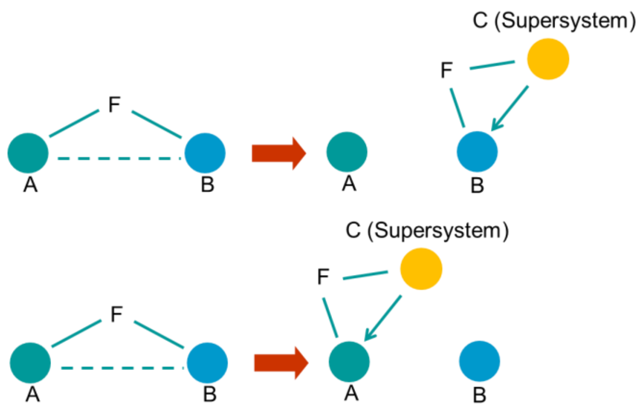
To illustrate how inventive standards are presented in ISBM, we present several inventive standards from the ISBM system developed in 2015 (Table 2). As in the classical Altshuller's system, each inventive standard is accompanied with one or more examples of specific solutions to better explain meaning and applicability of an inventive standard.

Table 2

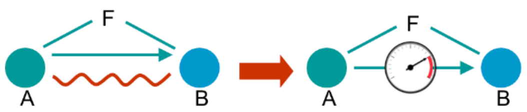
Randomly selected Inventive Standards from each group

Group 1: Standard 1-4:		
1-4	**If there is an insufficient (ineffective) effect of interaction between two objects A and B, and it is not possible to introduce a foreign object, analyze if there is already any object(s) in the existing environment of objects A and B which property can be used to achieve the desired effect of the interaction. The existing object can be used as available system resource to boost, accelerate or amplify the effect of the insufficient interaction.**  Explanation: If it is not possible to introduce a foreign object to your system, study what resources (material, energy, information, knowledge, human) a system already has to which your objects belongs. In many cases, the environment within a system has readily available resource with a property to "amplify" the effect of an interaction without changing other conditions or introducing additional objects to the system. In this case, a main principle behind the interaction (usually, a process which provides the interaction) does not change. However in some cases, the resource object can provide a new field.	*Example: Using the company's disposable paper coffee cups to print company news on the cups to keep the customers continuously updated in order to improve information flow from management to employees.*
Group 2: Inventive Standard 2-1:		
2-1	**If there is an excessive effect of interaction between the objects A and B, introduce a new object between the two objects, which possesses the property to withdraw the excess of the interaction while providing only the necessary degree of effect (filtering), or to redirect only the needed part of the interaction.** 	*Example: At a large company, all feedback information arriving from the department employees would overload a department manager. To solve the problem, the manager assistant position is introduced to deal with growing information flows and selecting those critical issues that should be forwarded to the manager.*

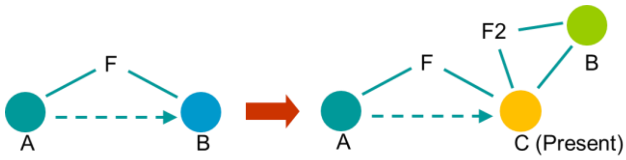
<table>
<tr><td></td><td>Explanation: Excessive interaction is different from the harmful one because it does not directly produce a negative effect or the negative effect produced can be neglected, but we would still like to have some optimal effect as a result of interaction. A foreign object has to become a kind of a “filtering mediator” which would receive an action from object A and transfer the action on object B without excessive effects that would accompany the excessive interaction. Often, the excessive action is not allowed due to some negative effect that would be caused by the existing type of the flow providing the interaction. Analyze what attribute of object B has to be changed, and find such a mediator that would convert the flow from the object A to another form but the required change of the object B would be achieved.</td><td></td></tr>
<tr><td colspan="3">Group 3: Inventive Standard 3-4:</td></tr>
<tr><td>3-4</td><td>If there is a poorly controlled effect of interaction between two objects A and B, consider replacing an object A or object B with object C that resides in supersystem.



Comment: A field behind the interaction can remain the same or can be replaced with a more effective field (e.g. replacing manual control with automated control).</td><td>Example: In case of a project, which requires specific competence not available in the organization, the competence can be brought by hiring an independent expert.</td></tr>
<tr><td colspan="3">Group 4: Inventive Standard 4-8:</td></tr>
<tr><td>4-8</td><td>If there is a harmful effect resulting from positive interaction between two objects A and B, and if the object is subjected to harmful or hazardous actions within the process of the interaction, consider conducting the process at a very high speed.



Explanation: Many processes are accompanied with harmful or undesired effects due to the nature of the processes. These factors can be removed or considerably reduced if the process is conducted at a speed significantly greater than the current speed of the process.</td><td>Example: Restructuring a department can be a painful process if performed slowly. It is suggested to produce restructuring within the shortest term possible</td></tr>
</table>

Group 5: Inventive Standard 5-4:		
5-4	**If a certain parameter is difficult to detect or measure, a problem can be solved by indirect measurement or detection of another object or a field present in the system, change of which depends on a change of the parameter to be measured. Instead of direct measurement or detection of the parameter needed, another parameter identified with the first one is measured or detected.** 	*Example: It is difficult to directly detect an exact moment when a supplier shipped the needed materials through the courier mail if a supplier has not provided information to a customer timely. However, it is possible to learn about the shipment by requesting service from a postal company used by the supplier which will alert the customer each time the shipment has been made.*

3. Practical Applications

Currently, the ISBM system is used in two types of TRIZ-related activities: training and innovative problem solving. The ISBM system has been taught regularly since 2012 at training workshops on TRIZ for business and management worldwide for business professionals [12] (fig. 5). The system has been accepted rather well, despite the lack of technical background by many students. Often, students find successful solutions to real-world problems which they bring to a training workshop.

Regarding application of ISBM for solving real problems outside the training activities, during last several years, a number of solutions were obtained with different categories of customers. Such solutions mostly addressed resolving conflicts either within an organisation, or between an organization and its supersystem, for example, a supplier or a customer. Sometimes ISBM was used to improve customer relationships, enhance a product image, increase revenues, and so forth. Unfortunately, the size of this paper does not allow us to demonstrate these cases in detail.

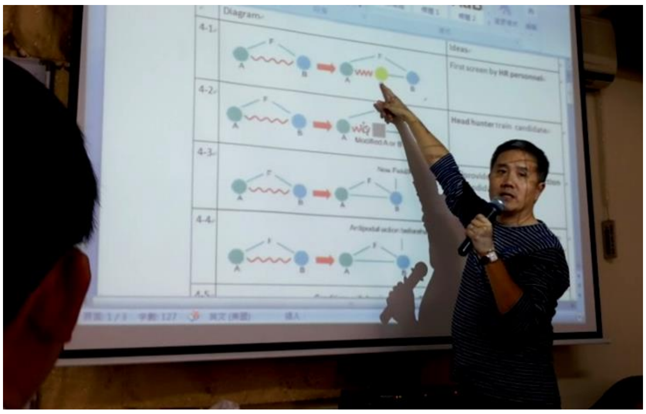


Fig. 5. Applying a System of Inventive Standards for Business and Management to solve a real problem related to improvement of training business during training process. Hsinchu, Taiwan, December 2015.

4. Conclusions

Fast and efficient solving of non-standard, "inventive" problems becomes critical for survival and development of virtually every business. Today many business professionals start to realize that traditional ways of innovative problem solving which rely heavily on random methods of idea generation like brainstorm may look fascinating and inspirational, but they often lead to considerable waste of time and resources, as well as to making incorrect decisions. New systematic and structured methods supporting continuous process of new business ideas generation are demanded.

Problems can greatly vary in scope: for example, one problem is how to resolve a local conflict between a manager and an employee at a start-up, while another problem is how to increase worldwide sales of a product by a large multinational corporation. However, despite the scale, solution patterns to both problems may be identical. Knowledge of such patterns drastically accelerates search for solutions close to ideal and enhances personal problem solving skills.

In summary, the ISBM system has the following features:

- No need to learn TRIZ for technology and engineering. Basic TRIZ concepts and fundamentals as well as basic concepts and fundamentals of ISBM system can be learned directly for business and management.
- Language used is understandable within business and management environments.
- Classification between problem categories helps to quickly move to the group of inventive standards which is most adequate for solving a problem required.
- Examples are brought from the areas related to business and management.
- The system can be used for solving problems of various scale and used both by large and small businesses.
- The system can be used to solve all types of problems causing conflicts even if such problems are not recognized as "innovative".

Further development activities will focus on refinement of Inventive Standards included and organization of ISBM system propsed, as well as with extracting and structuring new patterns. In addition, work on the improvement of a theory of "fields" for business and management areas is scheduled.

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ACCELERATED TRIZ PROJECT EXECUTION

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Abstract

Many companies propose three types of TRIZ-based services: project execution, group facilitation and training. The Main Parameters of Value (MPVs) of these services are determined and their respective performances are subjectively evaluated. It is possible to improve training and group facilitation services by combining them with other services: this usually corresponds to the current formula proposed by the best TRIZ consulting companies. As for the improvement of project execution, some practices for the enhancement of MPVs except cost are given. Besides, the limited cost often wished by clients for this service puts the TRIZ consulting companies in face of a contradiction between cost and quality of developed ideas. The resolution of this contradiction leads to the development of the accelerated project execution. In this type of service, a specific accelerated roadmap for product innovation which contains the minimal number of useful TRIZ tools is designed for each project. Accelerated project execution is also based on the dynamic selection of the most promising conceptual directions, key problems and ideas to be developed. Some hints for this selection as well as some sanitized examples are given so as to help the TRIZ practitioner applying this necessary type of project execution in the current context of cost pressure in the global economy.

Keywords: accelerated, training, group facilitation, project execution, contradiction, cost, quality, main parameter of value

1. Different TRIZ-based services

A lot of companies around the world propose TRIZ-based services, actually – for the sake of simplification - three main services:

- Project execution: the consulting company takes the responsibility of the results and delivers them to the client. This is the most current TRIZ service.
- Training: the consulting company trains the client in the theoretical and practical aspects of TRIZ. This is the second most current TRIZ service.
- Group facilitation: the consulting company facilitates a group with the help of the TRIZ method, so that the client generates the results. Theoretically the group is not familiar with the TRIZ method, or at least not trained. This TRIZ service is rather rare.

These services are in relationship with what can be actually done for or by the clients. Here is a list of typical applications of the TRIZ method:

- Sustainable and/or radical innovation of a product or process;
- Prediction / roadmapping of technologies;
- Intellectual property enhancement (patent fencing, patent circumventing);

- Identification of new applications / new markets for an existing technology;
- Identification of the causes for a failure / anticipation of failures.

The scope of the present article will be the sustainable and/or radical innovation of a product (or a process considered as a product), because this application is often asked for by the clients.

2. Determination of MPVs for TRIZ-based services

The situations of the companies which are potential or real clients of TRIZ services usually differ a lot. However one may generalize and affirm that these companies consider the following MPVs (Main Parameters of Value) [1] for such services:

- 1/Cost. This is especially true in the current post-2008 era: the economic crisis is not over, the companies and their shareholders want a quick and high return on investment more than ever. In this context all the costs (materials, equipment, salaries, services …) are under pressure.
- 1/Time to results. Usually when the client decides to go for a TRIZ service, he wants that it begins soon, and that the results arrive quickly, typically within some weeks or months.
- 1/Time devoted by the client (in men.days). As an example, for a project execution, a client always asks how much time its team should devote to the project: actually the client should take some time to explain its challenge, to answer some precise questions, to participate in meetings, etc. But this time should be limited.
- Quality of the developed ideas. This depends much on the function of the client within the company. Two extreme cases may be considered:
    - The production manager needs at least one idea that can be readily applied in the factory with success, so as to reduce production costs, improve productivity or eliminating a harmful effect, for instance.
    - The R&D manager usually wants several innovative solutions which will help him designing future products or processes.
- TRIZ skills developed by the client. It is often wanted by the client to incorporate the TRIZ method and associated skills. This is not possible with any type of service.
- Results appropriation by the client. This aspect may be particularly critical in the context of project execution. The results may be great in reality, but if the client doesn't appropriate the results, proposed solutions may be not tested and therefore not implemented for that mere reason.

These MPVs given by the author are based on his experience, and therefore subjective. Some MPVs may be correlated. Some MPVs may be contradictory. In Table 1 the MPVs' performances are subjectively estimated for each service, as low, average, or high. The performance of MPVs must be maximized therefore three inversed formulations have been defined above. Note that the following assumption has been considered for the sake of comparison: after training, the trainee applies what he learned on his project: he analyses and develops his own ideas; this work can be partially done by a team of trainees.
Note also that we have omitted as MPV the credibility of the TRIZ consulting company, which is not relevant in the present study, but is clearly key for the purchase of its services.

- Project execution is meaningful for companies which don't have / don't have yet the will to train their employees to TRIZ. There may be different reasons for this lack of will:
    - They don't know TRIZ yet. Often project execution is a way for a company to test the TRIZ method while testing the consulting company.

- o They believe to know TRIZ and may have an internal "expert" who actually has a poor knowledge and practice of the method. They may also think that TRIZ doesn't work for their field. However they are open to re-test the method.
- o They are too little companies, or production facilities, which don't see any interest to learn TRIZ because they consider that they will need the method not often enough: the day-to-day of a factory should be first concentrated on quality and productivity.
- o They believe they can solve most of the challenges they face without any method.

So project execution:

- o Is a good way to test TRIZ and get a first acquaintance with the method. It is usually recommended to take a tough challenge which is well defined.
- o Is good for companies, in R&D or production, which need a punctual help for tackling technical challenges that are too tough for them, or for which they have a current lack of human resources.
- o Is adapted for challenges for which the expected return on investment is important, because it is costly.

Table 1. Evaluation of the MPVs of the three main TRIZ services

MPVs	Project execution	Group facilitation	Training
1/Cost	Low to Average	High	Low
1/(Time to results)	Average	High	Low to Average
1/(Time devoted by the client)	High	Average	Low
Quality of developed ideas	High	Average	Low to High
TRIZ skills developed by the client	Very Low	Very Low	Low to High
Results appropriation by the client	Low	High	High

3. Current status and possible improvement of the TRIZ-based consulting services

Even though it would be possible in another context, the intent of the present article is not to perform a systematic study of the TRIZ services themselves, with the help of the TRIZ method. Rather, the evaluations given in Table 1 are commented below, and they constitute a starting point for the improvement of the main TRIZ services, in particular for project execution.

3.1. Training

Training may be very costly, depending on the number of trainees and the MATRIZ level to be reached (1, 2 or 3) (MATRIZ levels are considered here, for they constitute a popular standard; other standards exist and the proposed approach in the present article is standard-independent). Therefore it must often be seen as a mid-term to long-term investment for companies which aim at internalizing TRIZ, so as to execute themselves their projects and at the end, so as to systematically innovate. Training is naturally devoted to people who work in R&D and innovation. It is less naturally devoted to a production context. "Time to results" can be defined as the time duration between the first training (level 1) and the end of a project that

is executed by trainees, independently from the trainer. This time duration may be very long. Accordingly the “Time devoted by the client”, which integrates the training time plus the internal project execution time, can be long. “Quality of the developed ideas” usually grows with the educational level of the trainees (including the solving of educational TRIZ problems) and above all with the repeated thorough application of the TRIZ methodology on internal projects, i.e. with the increase of the “TRIZ skills developed by the client”. Therefore these two MPVs are evaluated from low to high. Finally, of course, the appropriation of the results is maximized because the trained people generate their own ideas.
So as to increase substantially the three first MPVs of Training, one of the best known training formula proposed by the best TRIZ companies (the following has been done for General Electric for their implementation of TRIZ [2]):

- Includes during the training a direct application of the learnt TRIZ tools (for analysis, solving, ranking of ideas and concepts…) on projects brought by the client. The client is helped by the trainer who turns into a facilitator. Obviously it is impossible to explore all innovation opportunities during that short time.
- Suggests a subsequent full application of the TRIZ tools on the projects that have been only partially executed during the training.
- Proposes a mentorship so that the trainees can ask for punctual advice or help about the correct application of the TRIZ tools.

It is interesting to note that this best training formula includes both project execution (by the client) and group facilitation: it is a hybrid service.
In the long run, training allows developing internal experts which are at the level of TRIZ consultants and which cost less.

3.2. Group facilitation

Group facilitation has the main advantages of its quickness and the fact that the client really feels as the owner of the results, because he has generated them. However in its pure shape (i.e. the facilitator discovers the subject during facilitation, and he doesn’t work out of this facilitation time) this type of service can be very risky for the consulting company and at the end for the client because the quality of the developed ideas may be disappointing because the necessary time limitation makes impossible to:

- Deploy properly all the necessary TRIZ tools, especially analytical tools. Therefore the conceptual directions cannot be fully explored and accordingly interesting innovation opportunities may be easily missed;
- Search thoroughly for disseminated information; also, search for information is easier when performed by an individual rather than in group.

Thus, although it is an interesting way to tackle technical challenges and solve problems quickly within a group, group facilitation is great if it turns out to be a success but is rather risky and can be damaging for the image of TRIZ if it is not the case. So as to reduce this risk, i.e. to increase the “quality of the developed ideas”, group facilitation can be improved by a parallel, partial project execution by the TRIZ consultants. As such, it may be a more secure way to introduce TRIZ to a company than group facilitation alone.
Otherwise a completely different model is to facilitate groups that are already literate in TRIZ, on a specific project, or to propose them targeted mentorship. Finally this approach is more to be considered as a complement to the former training model.

3.3. *Towards accelerated project execution*

The disadvantages of project execution are numerous, but the alleged most important MPV, the "Quality of the developed ideas", can have a high performance if some conditions are met. Among these conditions are:

- An efficient team of TRIZ consultants.
- Sufficient time devoted to the project by these TRIZ consultants.
- An efficient transfer of the necessary information from the client to the TRIZ consultants.

The latter condition allows the TRIZ experts to become "pseudo-experts" [2] of the set challenge to tackle or the problem to solve, in a very short time. Of course this is the art and duty of the TRIZ consultants to ask precise questions to the client. Accordingly the time devoted by the client for information gathering and different meetings and teleconferences can usually be kept limited and under control.

Can the "TRIZ skills developed by the client" be increased in this context? Honestly it is not possible under this format without proper training. Without substantially increasing the performance of this MPV, the experience of the author shows that:

- A 2 to 4 hours introduction to TRIZ at the beginning of a project, with high-level explanations of the project roadmap and the corresponding tools, can help the client to begin his understanding of the TRIZ methodology. For instance TRIZ consultants may insist on some important TRIZ principles, like those of psychological inertia or function (as defined by modern TRIZ) by playing short games. Also the illustration of the concepts of contradiction and trends of evolution on the basis of problems and solutions from the field of the client can strike his mind.
- During meetings and/or teleconferences, essentially outputs of TRIZ procedures are presented, e.g. key problems at the end of the analytical stage, and individual ideas at the end of the resolution stage. The TRIZ consultants explain thoroughly how the TRIZ tools helped them defining a sample of key problems, and some individual ideas, respectively.

It has been experienced on the most costly executed projects, that doing so, even if the client doesn't develop practical TRIZ skills, it changes the vision he has about engineering and his field and accordingly, to his job: in short, the set of technical innovation opportunities seems to him wider afterwards.

Can we increase the "Results appropriation by the client" in this context? Fortunately yes. Actually this is much easier to perform with a former client, otherwise on a longer project. But even on short projects for first time clients, this is possible. The main idea is parallel to the former attempt sensitizing the client about the TRIZ methodology: it is about implying the client as much as possible in some project execution activities, for example as follows:

- Cautiously refine the definition of the project with the help of the client (objectives, scope, requirements, constraints…).
- Ask about the preliminary attempts of the client to solve the problem or tackle the challenge, and the causes for their partial success or failure.
- Determine obvious MPVs and their relative weights directly with the client. Possibly imply a client multidisciplinary team (engineers from different specialties, salespeople, marketers…) to investigate less obvious MPVs.
- Begin performing a functional analysis of the studied engineering system, and possibly the cause-and-effect chain of undesirable effects with the client, even if these will have to be completed by the TRIZ consultants later – especially the cause-and-effect chain of undesirable effects which usually needs several days of work to be thoroughly done.

- Ask the client about the relevance of the main outputs of the innovation roadmap, e.g. key problems, conceptual directions and individual ideas.
- Keep the client informed about your intermediary results and ask confirmation of their relevance.
- Be open to suggestions, modifications and critics formulated by the client about the key problems and ideas, and integrate them in your further work.
- Ask the client if he has other ideas to propose and integrate them in your list of ideas.
- Evaluate and rank the ideas with the client, if possible. Nevertheless make your own evaluation and ranking, and corresponding final presentation and executive summary for the top management.

The former activities take some time, but not so much finally, because it is part of organized meetings and teleconferences, so they turn out to be worth the minor additional efforts and time. Finally the client has participated in the process and this is a key.

As aforementioned, the cost of a project executed by TRIZ consultants can be high. If the price offered by the TRIZ consulting is linked to an estimated number of men.days to be worked by TRIZ consultants, and to a daily rate (this approach is not the best one for the TRIZ company, it would be much better to make offers based on the value that the TRIZ company brings, but this marketing and selling approach is uneasy, and this is another story), the cost is finally approximately proportional to these men.days (some expenses usually come on the top of that). Basically these depend on several factors concerning the project:

- Its objective: the cost is then in relationship with the complexity and difficulty of the project.
- Its scope: the broader the scope, the greater the cost.
- Its requirements and constraints may add to the difficulty and complexity of the project.

On the other side, the greater the budget that can be allocated to the project by the client, the bigger can be the amount of men.days. Theoretically, to some limit, this can help reaching the best quality of developed ideas. Beyond that limit, this doesn't help. But most often, the client has a limited budget, so the cost of the project is under pressure, and the TRIZ company which usually doesn't want to negotiate its daily rate must reduce the amount of men.days. The TRIZ company faces the following physical contradiction, which - if generalized - illustrates the universal contradiction between cost and quality:

PC: The amount of men.days must be low so that the project execution cost is low, but the amount of men.days must be high so that the quality of developed ideas is high.

Actually the client that has integrated TRIZ faces the same contradiction, whatever the level of expertise of its internal TRIZ experts.

As there is apparently no choice about the cost which must be low, the contradictory requirements of the physical contradiction PC must be satisfied (again, a thorough application of TRIZ is not the topic here: note that separation and bypass of the contradictory requirements are not explored). In other terms, we must solve the following problem: how to obtain a high quality of developed ideas with a low amount of men.days?

It is a good practice that the work of the TRIZ consultants is guided by an innovation roadmap which is customized according to the different parameters of the project (objective, scope, requirements, constraints), as soon as possible in the project timeline. The roadmap R is constituted by several tools Ti which may be parallel or consecutive. Each tool Ti receives an input Ei and delivers an output Oi.

It is interesting to consider a specific numerical function: the quality of developed ideas as function of the (cumulated) amount of men.days (it could have been cost). Figure 1 illustrates different situations for a given project:

- A purely hypothetical situation for which the ideal TRIZ consultant, after some incompressible time during which he learns about the details of the project, finds almost instantaneously the best innovative ideas for its client, in a stroke of genius. After that he goes on holidays. This may sound funny. However this may happen in the next decades thanks to the computing speed of a specifically trained artificial intelligence.
- A regular project execution, for which a usual, systematic roadmap R (as defined above) is applied by the TRIZ consultants. It is believed that the corresponding function evolves like an S-curve: after the incubation time which corresponds to the analytical phase, comes a rapid growth which corresponds to the beginning of the resolving / ideation phase. The function is shown smooth whereas in reality it may present some sudden, strong growth points which correspond to the discovery of the best developed ideas. The further growth decrease corresponds to the completion and refining of the conceptual ideas. For instance, a roadmap R of product innovation (for process innovation, a similar roadmap can be proposed) can contain the following tools Ti:
    - Analytical stage:
        - MPV analysis and discovery
        - Benchmarking of technologies (including patent analysis)
        - Function (and cost) analysis
        - Trends of engineering systems evolution
        - Trimming
        - Feature transfer
        - Flow analysis
        - Cause-and-effect chain analysis
        - Key problems analysis
    - Resolution stage:
        - Application of ARIZ
        - Application of inventive principles
        - Application of physical contradictions resolution tools
        - Application of standard solutions
        - Application of scientific effects database
        - Function-oriented search
    - Substantiation stage:
        - Secondary problem solving
        - Substantiation of individual ideas
        - Evaluation and ranking of individual ideas
        - Synthesis of concepts

- Evaluation and ranking of concepts

- A wished project execution, for which the maximal amount of men.days (corresponding to a lower cost) corresponds to a high quality of developed ideas. It is represented by another S-curve with earlier growth, and possibly quicker growth. This type of project execution which solves the aforementioned PC is called “accelerated” project execution.

The consideration of these curves, the regular roadmap R itself, and the accelerated project execution as practised by the author allows proposing the following general ideas:

- Some tools Ti should be partially or totally eliminated or trimmed.
- Some outputs Oi should be partially eliminated.

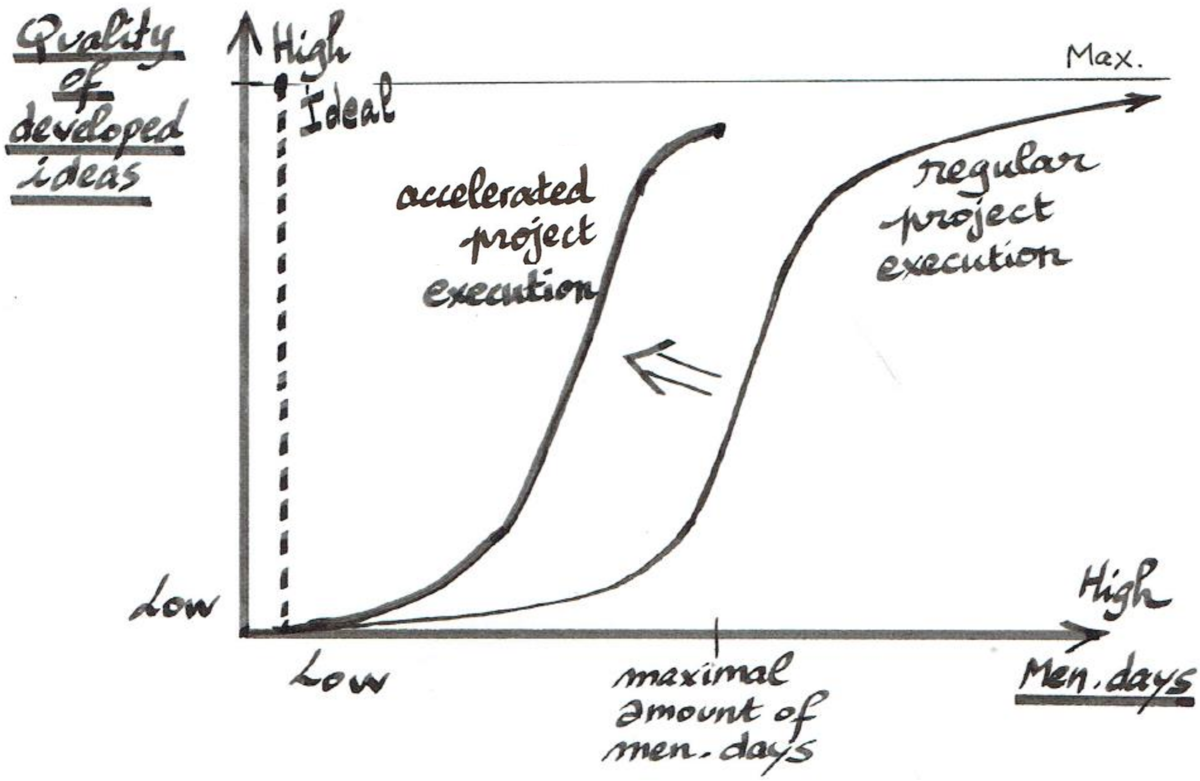

Figure 1: Different types of project executions: ideal, accelerated and regular

The former proposals are somehow equivalent to the value analysis or to the Pareto analysis of the roadmap considered as a process, i.e. theoretically the objective is to identify the tools and outputs which bring most value to the project. This is in strong relationship with the research goal of Oleg Feygenson [3]: to identify the 20% of the TRIZ tools which allow achieving 80% of the results.

Below are given several recommendations the aim of which is to increase the “accelerated” character of a project execution. These recommendations are of general nature, and are based on the subjective and general observations that the author made during projects executed for several French and Belgian clients (e.g. Nexans, Arc International, Dassault Aviation, LVMH, Ion Beam Applications).

Here are these recommendations:

- Design an accelerated roadmap R' which fits the needs of the project, and which skips superfluous tools totally or partially trims them. Depending on the project, its nature and its parameters, different roadmaps R' may be obtained. Finally the design of roadmaps and moreover of accelerated roadmaps is very much an art, a soft skill which can be developed over time. However, some general rules can be considered and in many cases it is possible to:
    - Postpone the MPV discovery which can be done more quickly after the application of several analytical tools.
    - Skip the patent analysis part of the benchmarking of technologies: a well-done search of technologies which carry the same function as the initial engineering system may be sufficient.
    - Skip the benchmarking of technologies itself, in the obvious case of a wished sustainable innovation (i.e. improvement) of an engineering system. In such a case, still radical innovation on a component is possible with other solving tools.
    - Skip the cost analysis part of the function analysis: in some R&D projects precise cost information can be difficult to gather. However it doesn't prevent from roughly guessing which components are the most costly, and the further application of the cause-and-effect chain analysis and of trimming and also the consideration of alternatives coming from the benchmarking of technologies, which can be very helpful in such cases.
    - Skip the trends of engineering system evolution (TESE) which can be long and tedious, because the number of these trends is big. An alternative is to use instead of TESE the analysis of the psychological inertia. Salamatov considers that several types of psychological inertia are carried out by any engineering system [4], i.e. by the mental image we have from this system. He recommends to carry out an analysis of the studied engineering system and its main characteristics, and to challenge these characteristics by setting the most childish question: why? Why is this characteristic so? Must it be so, or are there alternatives? These questions are equivalent to the purposeful shaking of the image of the system. In practice the use of this tool is quicker than TESE and brings similar results. Of course, this works for the TRIZ consultant who has already integrated the TESE in his mind.
    - Skip flow analysis. This tool is usually more interesting for process analysis.
    - Skip trimming, except if one wants to cut costs, simplify a design, reduce the duration of an operation…
    - Skip feature transfer in the case the benchmarking of technologies has not been done.
    - Skip ARIZ: in all projects performed by the author, ARIZ wasn't necessary. Nevertheless it may be applied in very specific situations in which even the TRIZ consultants are stuck or still dissatisfied after the application of other resolution tools.
    - Skip the inventive principles: this is a matter of personal preference, but it is possible to formulate only physical contradictions instead of pairs of engineering contradictions. Contrary to the recommendation of Altshuller that can be found in ARIZ, where it is recommended to formulate engineering contradictions first and find an underlying physical contradiction, the author

believes that both formulations are logically equivalent, and usually doesn't use the Altshuller matrix but rather the principles for the resolution of physical contradictions.

- Skip the application of standard solutions, which has turned to be unnecessary in most of the cases, in the experience of the author.
- Skip the application of a database of scientific effects. Here it is a matter of opportunity that cannot be decided in advance, and that depends on the list of key problems. So in the author's experience, this depends on the project. For instance it may turn very useful for the solving of a specific key problem for which function-oriented search and the principles for the resolution of physical contradictions turn out to insufficient. For instance, in the search for a new process for a client, an interesting scientific effect has led to the identification of a process which is not initially designed for the client's application. It could theoretically have been found with function-oriented search, but the latter tool may sometimes have its own limits which can then be complemented by the application of a database of scientific effects.

- Let the accelerated roadmap R' contain at least:
  - MPV analysis;
  - Function analysis;
  - Cause-and-effect chain analysis;
  - Key problem analysis;
  - Function-oriented search;
  - Principles for the resolution of physical contradictions.
- Skip one or two conceptual directions. Typically 20 key problems have been determined at the end of the analytical stage, and these key problems are grouped in 3, 4 or 5 conceptual directions. Usually solving the 20 key problems thoroughly can take a lot of time. In practice some specific conceptual directions may interest more the client because the other ones have already been investigated by the client, or seem less promising, or seem too complex, too ambitious, possibly out of the scope of the project. Let us give an example about a client which has a cleaning problem on a specific tool. The tool must be cleaned during repeated maintenance. The automatic process which is used has a cleaning efficiency of 80%. An additional, tedious manual cleaning work is necessary for the remaining 20%. Over the last 3 years, the client has worked on the identification of the zones which have been well or badly cleaned, without success. The client asks the TRIZ consulting company to search for alternative detection solutions, which answers that such a project execution is possible, but that a better project scope would be to find another way to automatically clean with 100% efficiency. After some internal discussions the client agrees with this last proposal to which is added the search for the causes of pollution of the tool, which remain unknown so far. During the analysis stage, the key problems are grouped into 3 conceptual directions: improvement of the current automatic cleaning system; alternative automatic cleaning systems; elimination of the pollution. The last conceptual direction is very promising, but the solving of the associated key problems promises to be very long, i.e. this defines a completely new research project or TRIZ project execution, which could bring big collateral advantages to the manufacturing process. Reasonably it is decided to give up this conceptual direction and to concentrate on the two others.

- Skip some key problems of remaining conceptual directions. In the remaining conceptual directions, the different key problems have not the same potential to bring interesting solutions. Whereas key problems are assumed to be inventive problems, some of them have a greater innovative potential for the client, if solved. Therefore such a selection is carried out between priority key problems and non-priority key problems. It is recommended to agree with the client about it. A very general guideline for this selection is to define as non-priority key problems those which belong to a not very promising conceptual sub-direction. The “not very promising” evaluation is based on intuitive, engineering judgment, and it means that one anticipates great difficulties for the implementation of the ideas still to come, or a low impact on the global performance of the concepts to be delivered. In addition, so as to monitor the solving of key problems, the TRIZ consultants may fill in a datasheet whether the quality of proposed ideas which solve each key problem is sufficiently high. Again, this is done before any quantitative evaluation and ranking of ideas: it means that engineering judgment and intuition help evaluating the ideas in advance, during the resolution stage.
- Develop only ideas which have the biggest potential. Again, following the same approach as above, only the ideas with the best potential are substantiated, i.e. deserve the writing of a specific sheet containing arguments for this very idea, e.g. the existence of a company which manufactures an equipment which fulfils the same function as the proposed idea.
- Solve secondary problems only for some promising conceptual ideas.
- Evaluate and rank carefully only the promising conceptual ideas.
- Develop some concepts, not all the possible concepts. One brutal force approach is to systematically consider all possible combinations of ideas. This can be time-consuming for no specific added value. Rather a sample of well-chosen combination of ideas can be much more interesting for the client. The main point here is to show the most interesting complementarities of technologies and ideas to the client. This has been done several times by the author for his clients with the help of a table with important functions in columns, and corresponding combinations of technologies and ideas in different, successive rows.
- Let the client evaluate and rank the concepts.

Let us remark that the proposed approach of accelerated TRIZ project execution in the present article is meant as a possible basis for further improvement by the TRIZ community. It is clear that every professional TRIZ consultant could share his own experience and observations in this area. Besides, a more systematic research on this topic would be welcome. One possible direction for improvement is to get inspiration from the agile (project) management techniques [5]. Doing so, for instance, the flexible and dynamic character of TRIZ project execution would be higher than in the approach proposed: the TRIZ tools themselves would not be chosen or skipped in advance in a specific accelerated roadmap R’; rather the next TRIZ tools would be chosen or skipped as the result of the outputs of the previously applied TRIZ tools [6].

Let us finally remark that the proposed approach can also be used for the economic benefit of the TRIZ consultants who make offers to their clients on the basis of the added value they bring, rather than on the amount of men.days; besides it can help them to increase their daily rate, if any their offers are so defined.

Conclusion

The three main services of TRIZ consulting companies, i.e. project execution, group facilitation and training, are analysed, their MPVs are determined, and the expected performances of their respective MPVs are compared. Current best practices of training and group facilitation services correspond to specific combinations of the three services. Some ways to improve project execution services are proposed. Maybe the most difficult problem to solve is the contradiction between cost and quality of the developed ideas. The solving of this contradiction under the constraint of limited cost leads to the so-called accelerated project execution. Based on the real practice of project executed for clients, and the general observations of the author, several ways are proposed, which altogether help the TRIZ practitioner to reach a high quality of developed ideas under cost pressure: design of an accelerated project execution roadmap for product innovation and practical dynamic selection of the most promising conceptual directions, key problems and ideas to be developed.

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AN ANALYSIS OF MARXIST PHILOSOPHY IN TRIZ THEORY

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Abstract

TRIZ is the innovation theories system which is integrated of technology system, technology evolution, ideal solution, physical contradictions, resources and functions. These concepts and contents include abundant thoughts of dialectical materialism. It will be helpful to understand and master TRIZ theory through study and analysis Marxist philosophy which contains the materialism and dialectics in TRIZ. It will guide creative work and practice, thus promote the progress and development of TRIZ theory itself.

Keywords: TRIZ, dialectical materialism, materialist dialectics, philosophy

1. Introduction

TRIZ, theory of inventive problem-solving, is called "super invention" and "Midas touch" by European and American experts. Practice has proved that TRIZ theory is successful use and solving a lot of problems in large well-known enterprises. It is a creative and effective tool to solve technical problems. The essence of TRIZ is not "manual type" knowledge, but in the deeper philosophical level [1]. Firstly, the philosophy and inner essence are analysed in TRIZ study. It will help us to master the essence of TRIZ theory and achieve the flexible use in real work.

2. Marxist philosophy and TRIZ

Marxist philosophy insists on the both materialistic and dialectical world view to know, explain and reform everything-including nature, human society and human thinking. Marxism reveals the general laws of the world: (1) the world is material; (2) the material world is the motion, change and development; (3) motion, change and development of the material world is regular; (4) people can know the laws and use laws to change the material world. Mr. Archie Schuler said that our minds should reflect the complex, active and dialectical developing world correctly. TRIZ innovation theory enriched the philosophical connotation of some laws of dialectical materialism such as the unity of opposites, the interchange of quality and quantity and the law of negation of negation [2].

2.1. The basic content of Marxist philosophy

Marxist philosophy adheres to the unity of materialism and dialectics. Dialectical materialism suggests that: material determines consciousness; consciousness has active effect on material; material and movement are indivisible; movement is the fundamental attribute of material; time and space are fundamental attributes of movement; time, space and movement cannot be separated. Dialectic materialism looks at the problem by related, developing and comprehensive view: contact means that mutual influencing, interrelated and interactional relations between elements and things; development is the forward movement and its essence means the creation of new things and the perdition of old things. Modern science has proved that everything is in extensive and universal relationship with the surrounding things via the exchange and transmission of material, energy and information [3]. The basic concepts of material, energy, information, time, space, connection, development, contradiction and law constitute the foundation of Marxist philosophy.

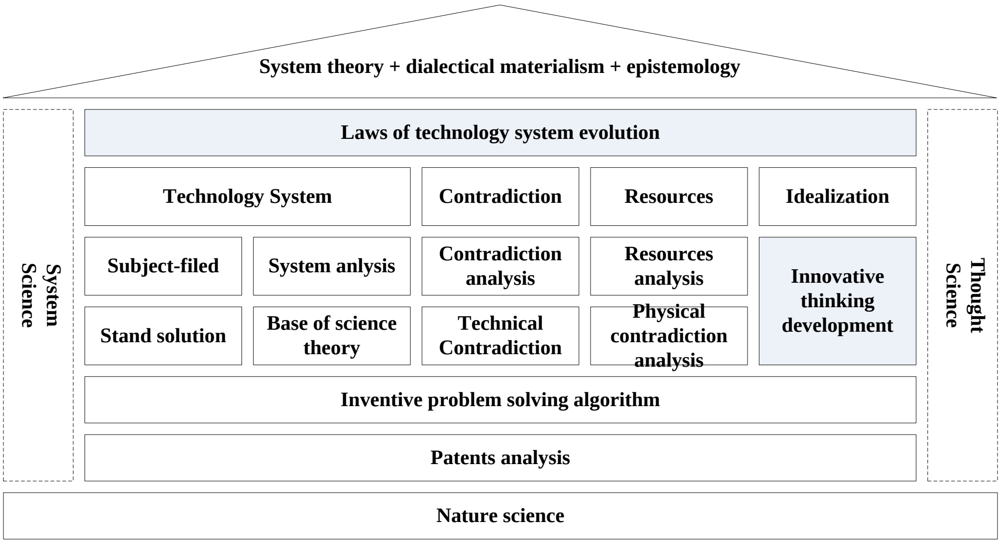

Fig 1. The Classical TRIZ theory system

2.2. *The frame of classical TRIZ*

Classical TRIZ is mainly composed by nine contents: the evolution laws of the technical system, IFR ideal solution, inventive principle, engineering parameters & contradiction matrix, physical contradiction &separation principle, object-field model, standard solution, ARIZ inventive problem solving algorithm and scientific principles effect database [14], as shown in figure 1. TRIZ is a complete innovation system based on dialectics, system theory and knowledge.

2.3. *Studying TRIZ and Marxist philosophy*

The concept and content of TRIZ are very abstract, but the problems in innovation practices are specific. Actually some people which are trained by abundant classical TRIZ theorem were confused to solve practical problems, because they did not understand the nature of problems well [7]. We should take the abstract philosophical concept in TRIZ as a powerful weapon to solve practical innovation problems. Analysing the relationship and difference between the content conception of TRIZ and Marxist philosophy, and understanding the dialectics and materialism of Marxist philosophy in TRIZ are significant to understand and master TRIZ.

3. The dialectical and materialistic basis of TRIZ

3.1. *The unity of theory and practice implemented by TRIZ*

The unity of theory and practice is the most basic principle of Marx doctrine. TRIZ is founded by Soviet inventor, Genrich S. Altshuller, in 1946. By analysing 2.5 million patents, A TRIZ theory system has been established, which contains kinds of methods and algorithm for solving technical problems and realizing innovation development [6]. Invention patents are the summaries and distillations of human creative activities. TRIZ, comes from a mountain of invention patents, is the development and sublimation based innovation practice. The practices have proved that TRIZ theory has been helped many famous enterprises with solving problems. Many enterprises of the world's top 500 have their own TRIZ innovation teams. TRIZ has become an effective tool to solve technical problems [12]. Meanwhile TRIZ is constantly developing and perfecting through the innovation practice. The positive circle of TRIZ between building the innovation theory system by analysing patents and guiding the innovation practice is the specific cognitive process of Epistemology in Marxist philosophy.

3.2. The objectivity of technical system and function

The system which is defined by the great scientist, Tsien Hsue-shen is an organism with specific functions that is composed of interactive and interdependent components. The popular book of classical TRIZ defined the technology system as: technology system refers to the human design made for a certain function of a synthetic system [16]. TRIZ is an evolving application discipline for studying project and other artificial systems [2]. The research object of TRIZ theory belongs to the engineering technology system which is established for a specific purpose. System science deemed that real things exist by the way of system: thing is system, and in the system. TRIZ theory analyses the composition and structure of reality on problem analysis and solves the problems by changing the composition and structure of the system. It is objective reality in artificial system that the TRIZ studies and problem solving through objective technology.

For the technology system, TRIZ thinks that it is important in the function of system not in system itself. System function refers to character, ability and function in the connection and interaction between the system and the external environment, also is existing purpose of the system. System science and TRIZ theory highlights the significance of function. TRIZ theory deems that function is the effect of technology system to maintain and change the attributes of the object, is the soul and existence value of the technical system. Function is attached to technology system, and is not the same as technology system. Technology system is the carrier of function, It and receptor must be material. Because of function as a kind of substance "properties", namely inherent nature of technical system, it is objective function.

3.3. The materiality of object-field model

In philosophy the material, belongs to the philosophical category of objective reality, is the entity of reality, which does not rely on the human consciousness, but can be reflected by human consciousness of objective reality. In the object-field model, the object is a complex program with arbitrary entities; the field generated energy flow, information flow, force flow, interaction, reaction, etc. [4]. Firstly, object-field model admit that the technology system is substantive and material, and is interactive between the object, rather than anything else. Therefore, the object and field are objective reality, and belong to the philosophy of material. All technology systems are composed of interactive objects. The object-field model is that the functions of component of technology system are analysed, value evaluated, value optimized to realize the innovation.

3.4. Science effect, resource are the view point of dialectical materialist

Dialectical materialism deems that the movements of thing are regular. And the regularity is universal, which can be understood and used by us. Scientific effect database is formed by analysing and summarizing scientific and different fields' knowledge in TRIZ. The complicated and profound science knowledge can be easily used by science effect database.

People can make use of the natural science knowledge directly to innovation practice, and no longer trapped in personal knowledge is limited to resolve the problem. Science effect in TRIZ theory becomes a powerful tool solve the invention problem by the motion law of objective things.

TRIZ theory deems that resources are everything in order to solve these problems. The objective existence which can be developed and used by human mainly include material resources, energy resources, information resources and time resources, spatial resources, resources function, system resources, etc. [4]. The matter is objective existence. The nature, social existence, and all sorts of things and phenomena belong to the category of the material and have the material property, such as sports, time, space, law, production mode, practice and its results. The use of these resources will be lower cost, but will bring a lot of unexpected beneficial effect. In Marxist philosophy, the abstract categories such as matter, motion, energy, information, time, space, connection, development, contradiction, law, are endowed with new contents and positive meaning in the theory of TRIZ, these will help us to break through inertial thinking and obtain creative thinking, will become powerful weapon to solve the problem and realize the innovation.

4. TRIZ conforming dialectical materialism

TRIZ theory analyses and solves the problem by the connective, developing and contradictory views. In TRIZ, concepts of technology system evolution, idealism, contradiction and resource are philosophical significant, based on the comprehensive foundation of dialectics, system theory, epistemology. It is similar to the dialectical materialism [11].

4.1. Innovative solution, the unifying of the opposites

TRIZ has a clear view: without solving conflicts, there is no innovation. Lenin believes that dialectics is a theory which studies the unifying of the opposites. Dialectical materialism study contradictory. The law of contradiction is the essence and core of dialectics. The dialectical materialism deems that any existed relationships of objects in reality are both opposite and unified.

If it can't understand the concepts of contradiction, and is not similarly understanding TRIZ [7]. TRIZ subdivided contradiction into management contradiction, technology contradiction and physical contradiction. There are technical contradictions in the management contradiction; technical contradiction can be transformed into physical contradiction by analysis. Therefore, it is important to solve the problems of physical contradiction. The physical contradiction will make two opposite requirements of the same parameter of a system or element. Therefore, physical contradiction includes at least two unities of opposites, namely the contradictions. The essence of physical contradiction can also think as other two aspects of technology system, form contradiction through the system conflict/elements. Materialist dialectics can realize unity of the contradiction of both sides thought by changing conditions. TRIZ theory solves the contradiction by invention principle.

To solve physical contradictions, we mainly use the separation principle: time separation, space separation, condition separation and system separation. Each separation principle contains several invention principles. Under the guidance of contradiction theory, the separation principle takes the contradiction as a unity and catches unity and harmony as the basis of contradiction, which promotes the conversion of contradictions [12]. TRIZ solves the physical contradiction by invention principles, implements the conversion and unification of the opposite sides under a certain condition and finally achieves innovation.

4.2. Idealism, ideal final result, technology evolution admitted the things are development and forward movement

The dialectical materialism of Marxist philosophy points out the developments and changes are showing obvious direction, forward and upward trend. Since 1970s, TRIZ developers has widely used some famous laws of dialectical materialism, such as the contradiction theory, the quantitative to qualitative changing rule, the negation of negation rule, to discuss the technology system evolution [13]. Idealism, ideal final result and technology evolution theory are the comprehensive application of above laws.

TRIZ believes that the evolution of a system always leads to the ideal direction. The evolution of technology system is not random, but follows the certain objective law. As the evolution of biological systems, the evolution of technology system also faces the natural selection and survival of the fittest. TRIZ proposes the idealism equals that the sum of all favourable factors by the sum of system cost and harmful factors. TRIZ holds that the opinion, invention is "out of thin air", is naive. In modern technology, there are tens of thousands of inventions in each system. It is necessary and important to consider realistic problems systematically, dynamically and interrelatedly. In one system, there are both favourable factors and harmful factors, namely the positiveness and negativeness. By continuously solving contradictions, increasing advantageous factors and reducing harmful factors, the evolution of technical system will be achieved, and which conforming to the contradiction theory. The idealization of the level of human thought will improve the product function, which conforming to the quantitative to qualitative changing rule. And the idealization is a process of the negation of negation.

Ultimately the ideal system which exists in subjective sense does not exist as a physical entity. But it clearly points out the direction of the development. The evolution of technology system admires that objects are development and forward. the ultimate ideal system is subjective consciousness. The contradiction of ideal and reality has become an important power to promote technology progress, is also active role consciousness, creative performance, and the main content about the relationship between physical and consciousness in dialectical materialism.

4.3. TRIZ innovative thoughts is the application of dialectical materialism

Connective view and development view are the general view and characteristics of dialectical materialism [2]. There are some classic TRIZ innovative thoughts: 9-windows method, miniature dwarfs method, goldfish method, ideal final result, STC, etc. The core of TRIZ innovative thoughts is that the world is a universal connective, developing and material world.

4.3.1. 9-windows method

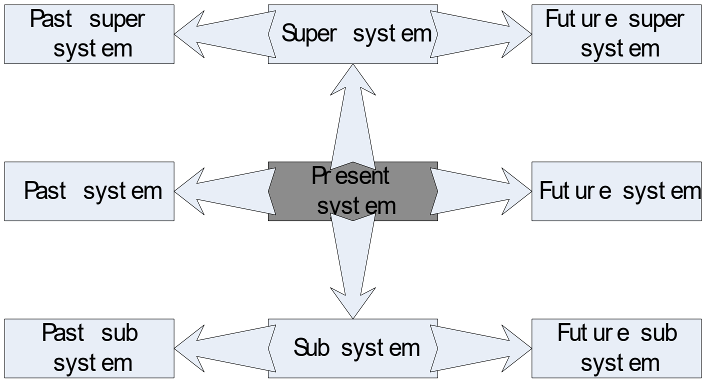

Figure 2. 9-windows

9-windows method divides 'the world' into nine segments as shown in Figure 2. With space as the ordinate axis, it sets the segments as system, sub and super system; with time as the horizontal axis, it sets the present system, past system and future system. According to the dialectical materialism, the internal and external factors are the basis and condition of object changes respectively. The object analysis should be taken from both internal and external aspects. The concepts of system elements, environment and condition in systematic theory are similar with 9-windows method. TRIZ theory holds that things and their interiors are interactive and interrelated in space and time. 9-window method directly shows the relationships among present, past and future situations, environmental and internal factors, which breaks the limitations of inertia of thinking. And 9-windows method considers things in a developing and interrelated view from time and space dimensions.

4.3.2. SIMS method

The system parts are represented with many active SIMS respectively. Different SIMS perform different functions or different contradictions. It allows them to play a role, execute function by combing these SIMS. If nine screen method is standing at the macro perspective, on the contrary, SIMS requires that thinkers think and look at things in micro angle. Because the real world we live is multi-level, the different conclusions are appeared from different view. Importing active *SIMS*, one person thinking will become many people thinking. It will be from macroscopic thinking into micro thinking. It will be more comprehensive and objective to see a problem, break through inertial thinking to make way for further widened.

Quality mutual change law of materialist dialectics thought not only the number change can cause qualitative change, the change of the structure can also cause qualitative change, the change of the structure is a form of quantitative change. Modern system science thought the function of the system related to the structure. TRIZ theory using the method of SIMS, through structure changes cause qualitative change to the solution of the problem, to achieve innovation and materialist dialectics point of view is consistent.

4.3.3. STC

STC means an innovative approach respectively considering the factors of space/size(s), time(t) and cost(c), and of which the essence is the application of quality and quantity changes. The law of quality and quantity changes describes the basic form and type of development, namely the quantitative changes and qualitative changes. According to the most basic attributes of time, space and cost of material objects, STC operator finds the solution via the dialectical relationship between the quantitative changes and qualitative changes. Based on this we know that as long as the change of a parameter or element in a system exceeds a certain limit, the quality change will be taken place, which brings the contradiction transforming and achieves solution.

4.3.4. IFR

The goal of a system is relationship between regularity and periodicity of system development, showing the direction of the system development [12]. The ideal final result(IFR) puts practical restrictions aside and builds an ideal model with the ideal system, ideal process, ideal resources, ideal method, ideal machine, etc. By the ideal model structure, problems will be analysed and final solution will be found. According to the technology evolution theory, TRIZ sets the goal and direction of the development technical system, which guides thinking and promotes problem solving.

The dialectical materialism thought that the world is changing and it look at problems from the view of development. Before thinking, the ideal final result (IFR) put aside the reality problem of various constraints. The ultimate ideal model is established using the ideal system, process, resources, method, machine, material, namely the optimal ideal model to get the ultimate ideal results as the pursuit of goals. "The system purpose is the development regularity and the unification of the periodic system, and performs certainty of system development direction." [19] TRIZ theory confirms the developing direction and goals of technology system by technology evolution. In turn, development direction and goals are used to guide thinking.

4.3.5. Goldfish method

4.3.6.

Human initiative is that people can consciously set the goal of activities, create thoughts in mind, and turn them into reality existences by practical activities. The thinking process of goldfish method is an iterative decomposition process of mutual changes of quality and quantity. It separates the practical parts from the impractical solution, causing quantitative qualitative changes until the problem solving. Adopting the goldfish method is helpful to change the ideal solution into practical solution. Goldfish method makes full use of thinking initiative to discover the cause of contradiction, eliminate conflict conditions, and solve the contradiction.

5. Marxist philosophy, the core of TRIZ

5.1. Studying TRIZ, studying Marxist philosophy

Last delineation of TRIZ is made by Genrich Altshuller in the 1980s, including contradiction theory, inventive principles, standard solution, technical system evolution rules, ARIZ, functional analysis, tailoring, causal chain analysis, and so on[2]. In TRIZ theory, the abstract philosophy that is incomprehensible the philosophical concepts and ideas, specific and practical becomes specific and practical, and also is a useful tool to solve the problem and achieve innovation. TRIZ theoretical system, involving lots of contents, is difficult for people to fully understand in a short time [5]. Through the studies and analysis of the philosophical theory of TRIZ, especially Marxist philosophy, we can better understand and grasp TRIZ theory and apply it to guide our innovative work and practice.

5.2. Marxist philosophy guiding the development of TRIZ

In 2014, the international TRIZ Association revised the basic theory, and pointed out TRIZ is still in the process of further development [2]. TRIZ is summed up in the period of Soviet Union. Considering the history and times limitation, some content is no longer suitable for the present requests. And it is necessary to improve it [5]. Genrich Altshuller believed that, TRIZ is not a completed theory, but a theory to be improved continuously. Now, the world is in the third revolution of science and technology. TRIZ theory cannot solve the problems in current era of information technology, biotechnology, aerospace science and technology, energy revolution and must have innovation and development of TRIZ.

China's socialist construction based on Marxist philosophy has made a great achievement in the field of social science. A series of philosophical thought is formed. The rise of the system science and complexity science is increased a lot of new important content of Marxist philosophy. It promotes the continuous progress and development of TRIZ theory by the guide of Marxist philosophy.

5.3. China's unique advantages, TRIZ theory learning and development

China is at the key node of development from learning to innovation. The development and design person needs a set of efficient, scientific innovation theory to guide the daily activities. TRIZ, the complete innovation theory system, meets the needs of the modernization construction of China. The Marxism philosophy that is a basic theory in China and makes great achievement in Chinese construction also makes great progress itself. It can be a unique ideological advantage for studying the theory of TRIZ. Marxist philosophy and the TRIZ theory are consistent. They can learn from each other, promote each other, and make progress together. Learning TRIZ theory need to learn deep Marxist philosophy; Development of TRIZ theory, also need to Marxist philosophy thought as the instruction.

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APPCESSORIES AS NOVEL TYPE OF THE HYBRID DEVICES: DESCRIPTION AND TRIZ RECOMMENDATIONS FOR DEVELOPMENT

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Abstract

Appcessory is hybrid device consisting of at least three parts: smart phone, accessory device and special application (software component) required to perform useful function for interaction of the first two components. This novel type of device is evolving within the framework of Internet of Things (IoT) trend in such categories as products for home, health care, fitness, lifestyle and entertainment, automotive, agriculture, smart watches, retail, tags and trackers, toys, jewellery, productivity tools, and many others.

The article briefly describes this novel type of hybrid device and provides selected TRIZ trends and recommendations that can be used for the development of new appcessory products. The study is based on research of products of successful start-up companies and "most funded" and "most popular" products in Technology Category of various crowd funding platforms.

Keywords: Hybridization, Hybrid, Appcessory Products, New Product Development

1. Introduction

The definition of the word "appcessory" may seem very simple: an appcessory is a physical object that can interact with an app on your mobile phone or tablet [2]. But in reality the appcessory is a very complex category of hybrid devices consisting of at least three parts: a smart phone, a physical accessory device, and a special application (software component) required to perform a useful function in the interaction of the first two components. These devices are evolving within the framework of Internet of Things (IoT) trend, and their development is fueled by both by venture investments and crowd funding.

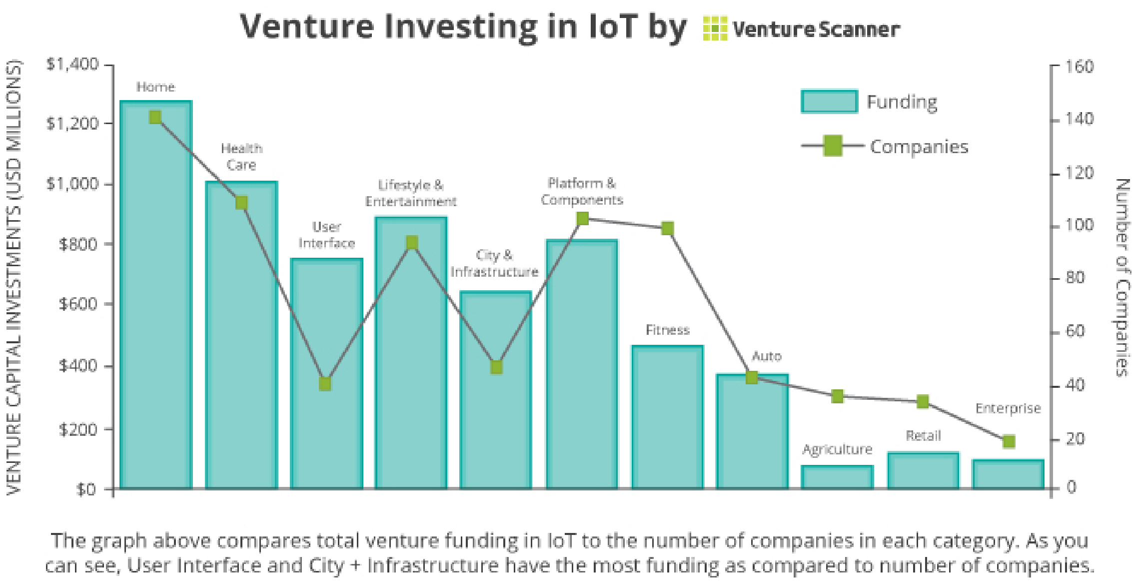

Fig. 1. Venture Capital Investments and Number of the Companies emerged in IoT

According to predictions [3], the number of registered Internet of Things (IoT) devices will exceed that of mobile phones in the next two years. This trend is fueled by rapid development of connected cars, and ironically, the connected car can be considered as one of the biggest appcessories. Given that most physical products are turned into the connected products, it is important to study trends of their evolution.

Since appcessories are hybrid products, the main question is why some appcessory products are good while others are useless to customers. However, the answer to this simple question is complex. Examples of appcessory products were studied and some of them were chosen and described below to explain selected TRIZ trends and make recommendations that can be used for development of this type of product.

2. Selected Examples and Trends

2.1. Applying Trimming Trend toward control organs

Since the appcessories are hybrid devices where one or more accessory (physical object or product) is interacting with a mobile device (smart phone or tablet), the key to creating an idea for successful product is distribution of User Interface between physical object and smartphone. Let us illustrate with an example of thermostat controllers from different developers.

The Nest controller (left side of fig.2) is considered by many specialists an exemplary device among the existing thermostat controllers. It provides to the customers the very convenient and complex interface of the physical device, that incorporate a rotating bezel, which is used to increase and decrease temperature. For additional convenience, a round touch screen is located in the center of the device. Also, temperature control is provided via the smart phone application, while additional control is available through the website.

The Tado thermostat/heating controller (right side of fig.2) has almost no control organs on the physical device, so users can only view the current temperature and adjust the temperature by using arrows. As one can see, the physical device has a very limited control interface. Most of the control is provided via the smart phone application.

Fig. 2. Nest (left) and Tado (right) thermostat controllers (Image source [4] and [5])

The development of control organs of the physical devices is much more expensive when compared with the development of smart phone interfaces. That’s why it is obvious that the way to trim physical control is to transfer them to smart phone UI.

Key steps of evolving of appcessories along the Trimming Trend are:

- Evolving from full extent of traditional control organs on physical object and providing additional User Interface via smart phone application instead
- Limiting control organs on physical object and extending control via smart phone application
- No control organs on physical object and full control via smart phone app and web site

2.2 Applying Hybridization Trend

Many innovations in the Internet of Things (IoT) area are only adding internet connectivity to traditional devices. It may not be enough to create a successful product that provides a meaningful user experience and improves the lives of customers. Take the example of connected lighting. Following the traditional line of thought, many inventors and developers proposed concepts of smart light bulb that are controlled via a smart phone up. However, this type of appcessory device has a limited market. In the case of smart lighting, more successful innovation is achieved via hybridization. One such successful appcessory product is the two-in-one light bulb with speakers. Most probably, the hybridization problem was how to achieve successful crossing of LED lighting with portable speakers and male screw of traditional incandescent light bulb in order to power the device. In addition, smart bulbs can be connected into smart lighting system and wireless speakers capable of playing music in each room with all systems controlled through a smart phone application.

Key steps to applying the Hybridization approach are:

- Studying super-system and environment
- Selecting prospective candidates for hybridization
- Applying hybridization algorithms (feature transfer, copy-and-paste, cut through, multiplication, etc.) to create novel concepts of hybrid appcessory device

2.3 Controllability

Appcessory devices are based on connectivity of physical object with smart phone or tablet. Some devices may be directly connected to the Internet. But many are not connected due to cost and power limitations. Currently, following types of local networking may be also used for appcessory devices [3]:

- Bluetooth. Classic Bluetooth requires maintaining a connection between the appcessory and smart phone and could drain the battery of appcessory device. Bluetooth LE (Low energy) is developed for devices with power constraints and transmits data at regular intervals.
- ZigBee and ZWave. Low-powered radio networks, suitable for battery-powered devices and designed for use in home automation. These networks can be extended through the mesh networking, extending the range of networking.
- RFID. Radio frequency identification uses electromagnetic fields to transfer identifying data from small tags to reader. Passive RFID has range 10-100 cm. Active RFID with own power source has range 10-100 m.
- NFC. Near field communication used for very short range (few centimetres) and that is why it is often used for mobile payments.

Due to power limitations, many appcessory devices connect to the Internet and thus to the smart phone not continuously, but intermittently. This can create small delays. This means that the appcessory devices will behave differently from the physical device. Also, internet connection can sometimes be unreliable.

Returning to the example of the thermostat controllers from different developers, specifically for observing controllability of the appcessory device, one can see an array of older generation devices with physical switches on the device, followed by mimicked switches on the screen of the smart phone. However, the Nest thermostat has “learning” capability, so after installation of the device, it asks the consumer to adjust the temperature of the home manually, so that the user is “teaching” the system his/her temperature preferences and “home” and “out-of-home” time by manual increasing and decreasing the temperature. The following week, after this “training,” the thermostat “learns” consumer behaviour by collecting the data, and offers the option to turn on “Auto-Schedule,” so that the device can control the system itself according to the consumer’s previous adjustments.

Key steps of evolving of appcessories along the improvement of Controllability trend are:

- Physical switching of device (i.e. manual control of the device)
- Smart phone application that mimics physical switches
- Self-controlling (self-learning) system

2.4 Import of Functions

One of the directions of evolution of the appcessory devices is importing functions performed by other systems. Many appcessory devices are not only connected to the smart phone or Internet, but also possess several sensors. This is particularly important for importing functions usually provided by super-systems. For example, an internet-connected robotic vacuum cleaner has a camera, and it is able to move around the house. In the framework of the smart home as a super system, it is natural for a smart-vacuum cleaner to import security functions, so it can provide to the owner access to the video stream of the home environment through the smart phone application. It is an especially attractive feature when the owner is out of the home and intrusion is detected by motion sensors.

Key steps of Importing of Functions are:

- Describe the existing appcessory system or its concept as it exists now
- List super-systems and their functions

- Identify how functions of selected super-system can be carried out by the new appcessory system using its sensors and other sub-systems
- Describe the concept of next generation of improved appcessory product

3. Conclusion and future trends

Based on observations of various appcessory products recently introduced by companies, start-ups and crowd-funding platforms, several trends important for their evolution were described. Since the evolution of physical products toward connected appcessory products is a common trend, it is recommended that innovators consider TRIZ insights about trimming control organs and taking steps along the controllability trend to greatly affects user interface. Also, applying hybridization and import of function trends helps to increase potential consumer base and increase the chances of product survival on the market. The recommendations that are summarized in table (fig. 3) can help innovators check the above-mentioned trends during the development of their own appcessory products:

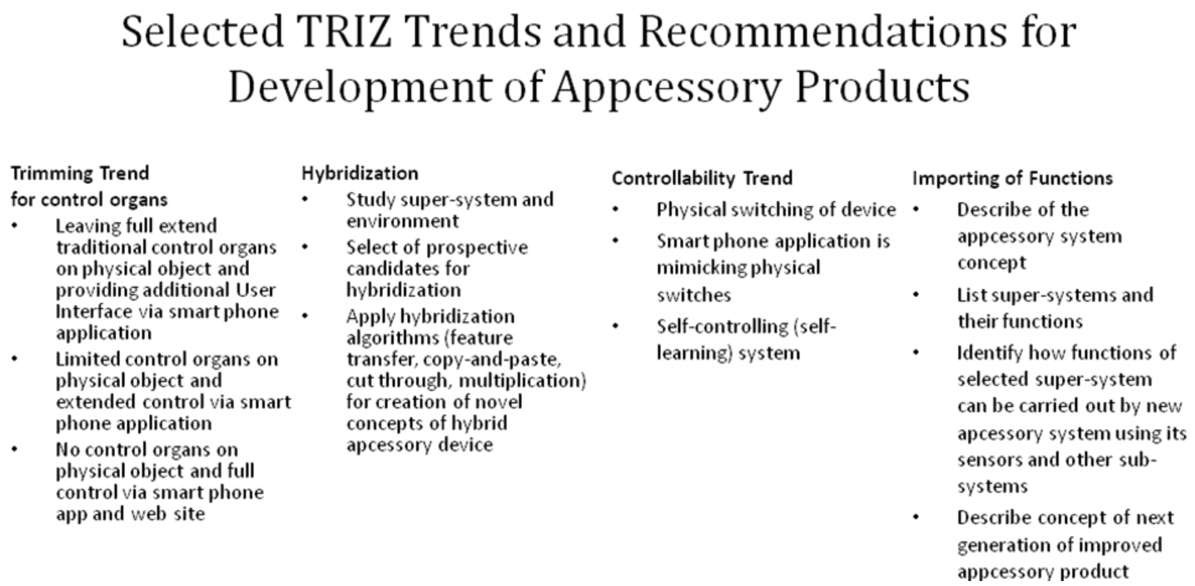

Fig. 3. Summary of Selected TRIZ Trends and Recommendations

Follow-up study for revealing of additional sub-trends in development of IoT and appcessory products is required, since continuous evolving of regular products toward connected products. Also, new sub-trends are regularly appearing due to steady progress of IoT products supported by numerous manufacturing companies.

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APPLICATION OF FLOW ANALYSIS TO STUDY LOSSES IN POWER TRANSMISSION & DISTRIBUTION

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Abstract

This paper aims to exploit Flow Analysis as a powerful problem identification tool in electrical power transmission & distribution (T&D) segment. Function analysis is performed on the electrical transmission & distribution system to understand the components and their functions. Type of flow was identified based on the level of function performance and type of performing functions. GEN3 flow partition model and operational flow model are built to identify the type of flow disadvantages. Based on the type of disadvantage, flow is analysed and recommendations are given to eliminate disadvantage i.e., in the current study to reduce the T&D losses.

Keywords: TRIZ, Flow analysis, transmission losses, corona losses.

1. Introduction

Power generated in power stations pass through large and complex networks like transformers, overhead lines, cables and other equipment and reaches at the end users. It is fact that the unit of electric energy generated by Power Station does not match with the units distributed to the consumers. Some percentage of the units is lost in the distribution network. This difference in the generated and distributed units is known as Transmission and Distribution loss. Transmission & distribution losses can be broadly classified into two categories – technical and non-technical. The technical losses are due to energy dissipated in the conductors, equipment used for transmission line, transformer, sub-transmission line and distribution line and magnetic losses in transformers. Technical losses are normally 22.5% [1], and directly depend on the network characteristics and the mode of operation.

This paper focuses on the technical factors resulting in losses in T&D. Technical losses can further be classified as permanent/fixed and variable. There are around a dozen fixed technical losses contributing to overall T&D loss. Minimizing the losses arising from transmission and distribution of power is one of the major challenges to achieve increased energy efficiency, sustainable living and reduction in CO_2 emission.

This paper aims to address the technical T&D losses from a TRIZ viewpoint by employing flow analysis to understand the bottlenecks and use flow trends to arrive at potential solutions to minimize the losses.

2. Technical Background

Fixed technical losses:

Fixed losses do not vary according to current. These losses take the form of heat and noise and occur as long as a transformer is energized. Between 1/4 and 1/3 of technical losses on distribution networks are fixed losses. Fixed losses on a network can be influenced in the ways set out below

i. Corona Losses
ii. Leakage Current Losses
iii. Dielectric Losses
iv. Open-circuit Losses
v. Losses caused by continuous load of measuring elements
vi. Losses caused by continuous load of control elements

Variable technical losses:

Between 2/3 and 3/4 of technical (or physical) losses on distribution networks are variable Losses. By increasing the cross sectional area of lines and cables for a given load, losses will fall. This leads to a direct trade-off between cost of losses and cost of capital expenditure. It has been suggested that optimal average utilization rate on a distribution network that considers the cost of losses in its design could be as low as 30 per cent.

vii. Joule losses in lines in each voltage level
viii. Impedance losses
ix. Losses caused by contact resistance.

3. Flow Analysis

Flow analysis is an analytical method and a tool that identifies disadvantages in flows of energy, substances and information in an engineering system [2][3][4]. Flow analysis was employed to categorize the major technical and non-technical losses of T&D into the two types of flow disadvantages – operational flow disadvantage and flow partition disadvantage.
Operational flow disadvantage are disadvantages relating to the level of function performance. They can further be classified as conductivity disadvantages and utilization disadvantages. Flow partition disadvantage relate to the type and number of performing functions. They are classified as harmful, wasted, inefficient usage of flows.

Table 1. Analysis of flow disadvantages for various T&D losses

Type of loss	**Technical loss type**	**Flow disadvantage**	**Details of flow disadvantage**
Corona	Thermal	Utilization disadvantage-Operational flow disadvantage	Other objects damage flow
Leakage current	Electrical	Flow partition disadvantage	Wasted flow
Dielectric loss	Thermal	Conductivity disadvantage-	Bottleneck

		Operational flow disadvantage	
Load losses	Electrical	Utilization disadvantage-Operational flow disadvantage	Gray zone
Joule losses	Thermal	Flow partition disadvantage	Waster flow

In this paper flow trend is used to come out with solutions in order to minimize Corona losses. Electric power transmission deals in the bulk transfer of electrical energy, from generating stations situated many kilometers away to the main consumption centers or the cities. For this reason the long distance transmission cables are of utmost necessity for effective power transfer, which in-evidently results in huge losses across the system. Minimizing those has been a major challenge for power engineers of late and to do that one should have a clear understanding of the type and nature of losses. Corona effect in power system is one such loss, which has a predominant role in reducing the efficiency of EHV (extra high voltage lines) [5]. When an alternating current is made to flow across two conductors of the transmission line whose spacing is large compared to their diameters, then air surrounding the conductors (composed of ions) is subjected to di-electric stress. At low values of supply end voltage, nothing really occurs as the stress is too less to ionize the air outside. But when the potential difference is made to increase beyond some threshold value of around 30 kV known as the critical disruptive voltage, then the field strength increases and then the air surrounding it experiences stress high enough to be dissociated into ions making the atmosphere conducting. This results in electric discharge around the conductors due to the flow of these ions, giving rise to a faint luminescent glow, along with the hissing sound accompanied by the liberation of ozone, which is readily identified due to its characteristic odor. This phenomenon of electrical discharge occurring in transmission line for high values of voltage is known as the corona effect in power system.

Corona loss is of importance only on high voltage lines of 345 kV and higher, because it is an effect caused by geometric enhancement of the electric field at the conductor surface, and the starting field is lower on lines of lower voltage class. Once a power line has been built, the only way to reduce the corona loss would be to reduce the voltage. While that is generally counter-productive in terms of system operation, there may be some situations in which a line is being rained on, is not heavily loaded and could be operated at a slightly reduced voltage. The corona loss changes as a power of the voltage, so for example a loss reduction of 25% may be achieved with a voltage reduction of perhaps 5% [6]. The 5% reduction in operating voltage increases the ohmic line losses by 10%. Therefore, reducing corona losses by decreasing the voltage could be implemented during periods of low line loading, if the benefits can justify the effort [7]. The overall impact on efficiency would be climate-dependent. Major sources of corona are voltage of line, radius of conductors, irregularities on the surface of the conductor, weather conditions, spacing between the two conductors, air pressure etc.

4. Results & Discussion

As Corona loss was one of the major factors affecting the efficiency of transmission of power, flow analysis was performed on it. The trend of flow enhancement [8] has 2 subtrends, each with 2 sub-subtrends:

1. Improve useful flows
    a. Increase conductivity of the flow
    b. Improve flow utilization
2. Reduce negative effects of harmful/incidental flows
    a. Reduce the conductivity of the harmful/incidental flow
    b. Reduce the impact of harmful flows

The corona losses, as is clear from the explanation in the previous section, falls under sub-subtrend 2b – reduce the impact of harmful flows. The different techniques listed by GEN3 Partners Inc. as potential paths to reduce the impact of harmful flows were studied and are discussed below.

1. Reduce the density of the flow: Voltage reduction is one of the ways of achieving reduced density of current flow. The disadvantage of this, though, is that this will lead to loss in the quality of the power transmitted. Another way is to for the same given current flow, employ larger diameter conductors which in turn would reduce the density of the current flow.

2. Eliminate resonance: Supply frequency in the transmission lines plays a vital role in the corona losses. Generally, the resistance in the interiors of the conducting lines are higher in comparison to the resistance of the exterior surface of the lines. This gives rise to increased corona losses. A change in the supply frequency to the effect that the difference in resistance between the interiors and exterior surface of the conductor decreases will reduce the corona losses.

3. Redistribute the flow: The flow of current can be performed by Creating a voltage gradient across the cross-section of transmission line such that the inner axis of the conductor tramsits higher voltage in comparison to the outer surface. Lower voltage along the outer axis that is closer to the atmosphere would lead to lower corona losses.

4. Modify the flow:
    a. Corona loss is known to increase with decreasing radius of the conductor. Hence, an increase in the radius of the conductor will result in a reduction in corona loss. But, the secondary problem that needs to be solved here is huge increase in cost due to bigger conductors to be deployed over a very long length.
    b. Corona loss can also be decreased by increasing the distance between two conductors. By increasing the distance, the skin effect and the interference of corona effect from the two conductors can be reduced.

5. Modify the damaged object:
    a. Anti-corona materials can be coated on the conductor in order to reduce the effect of corona losses. The constraint in this is that the solution is not practical for existing transmission lines. This can be implemented for transmission lines that are newly deployed.

b. The conducting wires can be dispersed with nano-materials of anti-corona materials. To account for the reduction in conduction due to presence of anti-corona nano-dispersoids, radius of the conductor can be increased correspondingly.

5. Conclusions

TRIZ based flow analysis was employed to investigate the losses in long distance power transmission. Flow analysis was performed to identify the type of losses, technical loss types, corresponding flow disadvantages and finally the details of the identified flow disadvantages. As a case study for flow analysis, corona loss was selected to further analysis. The subtrend corresponding to corona loss was identified and the potential solutions provided by GEN3 Partners [8] were employed to come up with solutions to minimize corona losses in the long distance transmission lines.

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APPLICATION OF TRIZ CONCEPTS IN TEACHING EFFECTIVE RESEARCH COMMUNICATION SKILLS

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Abstract

This paper proposes a new application of TRIZ concepts in the teaching of effective research communication skills. A pilot test was designed and implemented in a workshop organized by the authors. The participants of the workshop were Japanese engineering students who are starting to write their first papers for an academic journal. In the workshop, the TRIZ concepts of technical contradiction and function analysis were introduced as a tool for supporting clear definition of the student's research objective and the conclusion. The students could successfully use the proposed method to visualize the contradictions and to analyse the key components that form the core of their research. The activity helped the students clarify their core research objectives making it easier to communicate research content and thus save time when writing.

Keywords: Research Communication Skill, TRIZ, Technical Contradiction, Function Analysis, Academic Writing

1. Introduction

The ability to effectively communicate one's research through publishing in academic journals or conferences is one of the most important skills for university student. Universities also value publication of research in reputable English language academic journals for a variety of reasons including the responsibility to share research benefits with society to the need to improve their international standing.

In Japan there is little opportunity for use of English in daily communication. It is widely recognized that English language tests such as TOEIC, TOEFL and IELTS are important for improving and measuring English language skills. Greater vocabulary and grammatical knowledge tend to effectively increase the marks on these exams, but while it may be true that higher marks in these exams are a good measure for English learning, it is evident that many Japanese students still need still need support for their academic writing.

Many Japanese students usually need native checking before they can publish an academic paper. But even so, it is important for them to ensure that what they want to communicate is precisely communicated to the translator, and after translation, to check that the translation adequately reflects their message. Therefore, one of the most important skills for Japanese students in relation to academic writing is the ability to check whether the essence of what they want to communicate remains intact when translated to English [1].

Another essential skill needed even before writing is started is the ability to extract essential information from a wide variety of sources (such as from related work). In Japan, many engineering students usually begin to write a journal paper after multiple experimentations and trials, reading a large number of related studies and finally getting permission from their research supervisor to proceed. At this stage, the information collected by the student through literature reviews, discussion with colleagues and supervisors, experiments, simulations, analysis and result data are intricately tangled up together. This is where many students waste much time on writing and rewriting their papers, and when it comes to writing in English, the situation becomes worse.

In this paper the author's propose and experiment with a new method employing some TRIZ techniques in supporting students in their initial stages of writing academic papers. Basic TRIZ concepts such as solving contradictions, the 39 parameters and function analysis are used in the initial organization and clarification of research objective from the multitude of information obtained from the student's research work.

2. Past Academic Writing Workshops

For the past 2 years, the authors have been developing a workshop program tailored for engineering students at Nagoya University to learn important concepts for effective technical English writing. The authors started the workshop program focusing on grammar and vocabulary for technical writing in engineering specialized fields [2]. These workshops were later designed to be completed in a short time frame so as not to burden many of the students who were busy with tight deadlines for research paper writing and submission to academic journals and had no little time to delve into deeper English language learning.

The workshops consisted of three main sessions: Learning about the typical structure of an academic paper, Clarifying Objective and Conclusion, and using the 3C method (Correct, Clear and Concise). The workshop was attended by more than 50 participants. Below we briefly explain the content of each topic.

1.1. Typical structure of Academic Papers

In this session, the basic format of a typical academic paper was introduced. While there are slight variations (for example, some formats combine research background and research objective or analysis with discussion), the generally accepted classification of sections which is: title, abstract, background, objective, methodology, results, analysis and conclusion was used [3]. With examples similar to what is shown in Fig.1, the concept of a topic sentence and supporting sentences that form the paragraphs that make up a section of a journal paper was further explained. Participants were also encouraged to organize their paper such that topic sentences form a story and thereby making it easier for the student to write, as well as for potential readers to grasp the general content of an academic paper by perusing through the topic sentences.

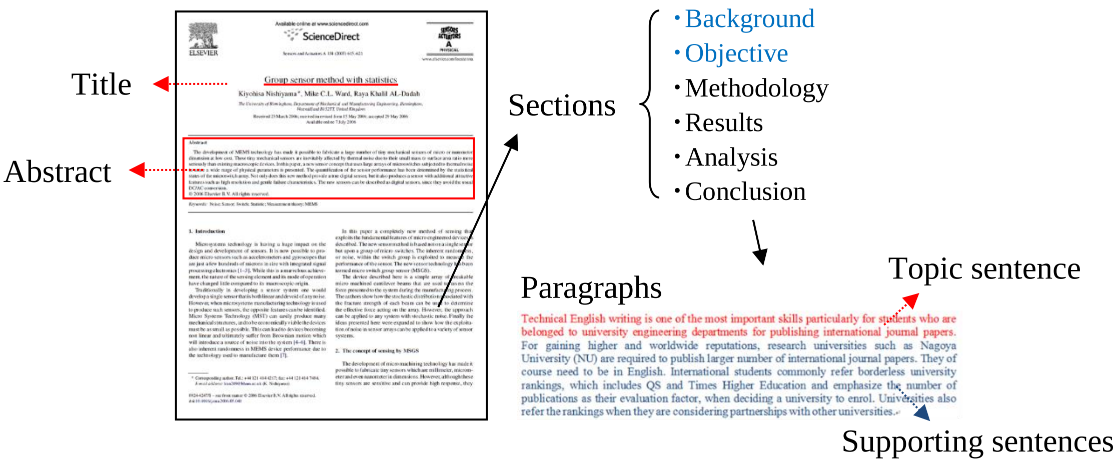


Fig. 1. Sections and paragraphs in a journal paper

1.2. Clarification of Objectives and Conclusion

Without clear guidelines, the authors have noticed that students in Engineering spend more time trying to create a simple flowing research story from their research outcomes. To address this, this session emphasized a process of writing where the students first create a clear research objective and conclusion, which are the two sections that form the core of a journal paper. The research objective relates to the social background and technical problems in previous research works which in turn forms the Introduction section. Similarly, the conclusion has the essential information for the sections of analysis, results and methdology. During the session, the participants are asked to describe their research objective and conclusion in one or two sentences. The process instructs an inexperienced writer to systematically select the essential pieces of information from the clarified objective and conclusion statements and expand into an academic paper. The topic sentences for most of paragraphs are also created through this process (Fig.2).

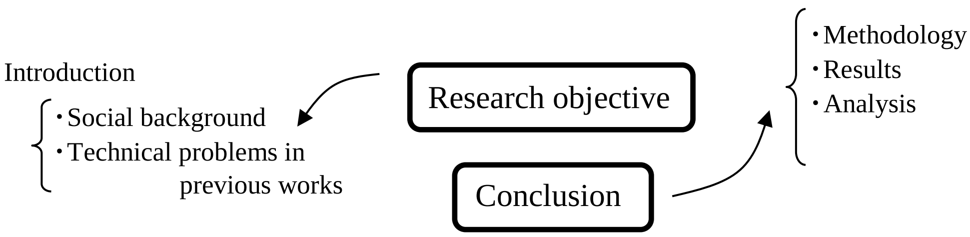


Fig. 2. Research objective and conclusion as core of a journal paper

During this session, the authors noticed that many participants kept struggling to define the research objective and the conclusion. Table 1 lists typical research objectives and conclusions given by the workshop participants. Here, XXX refers to some form of technology targeted in the research. A research objective, such as “to elucidate the mechanism of XXX”, may not have been the core research objective but a partial problem found in the experimental process during the research. Research objectives that were not clearly designed tended to limit the students ability to create a logical flow when attempting to write the conclusion. And conclusions derived from such misstated objectives tend to miss the point and limited the student’s ability to create a logical flow when attempting to write the conclusion.

Table 1

Typical research objectives and conclusions

Research objective	Conclusion
The objective of my research is to develop XXX.	XXX was successfully developed.
My research is aiming to elucidate the mechanism of XXX.	The mechanism of XXX was elucidated.
The goal of my research is to seek the possibility of XXX.	XXX may be possible.
This research is aiming to find effective methodology for XXX	Effective methodology for XXX was found.

1.3. The 3C method (Correct, Clear and Concise)

The 3C (Correct, Clear, Concise) is an English writing technique which stresses the importance of correctness, clearness and conciseness in technical English sentences. This method is popular among Japanese technical English translators. Japanese people prefer excessive use of difficult vocabulary and passive tenses in longer sentences which could be a result of the English education method in Japan. Though the technique may be one of the most useful in technical writing, it has not been widely taught in schools. The authors decided to introduce this technique as deemed it helpful for students trying to write technical papers while armed only with the grammatical knowledge taught in high school.

3. Application of TRIZ concepts in Research Communication

The authors' past workshops received positive feedback from the participating students. However, the authors noticed that there was a need to develop other workshop activities that can complement the above workshops by helping participants pinpoint and clarify their core research objective and conclusion.

According to TRIZ, most research is based on solving technical contradiction [4]. Although TRIZ is known as a methodology for innovation, the authors saw a potential for its use as a support tool for clarifying the research objectives and conclusions in technical writing. The following section introduces a preliminary workshop conducted with the aim of helping participants gain more clarity of their research topics using concepts from TRIZ.

Activity 1: Finding Contradictions

The authors designed this activity with the belief that recognizing contradiction embedded in research will help the participants get deeper understanding of what they want to communicate about their research. It is composed of the following 3 steps with the handouts shown in Fig. 3-5.

Step 1: The first step of the activity (Fig.3) asks the participants to write the purpose of the technology being developed in their research. Usually, when participants are asked for the research objective, the answers tend to be similar to those shown in Table.1. Focusing on the purpose of the technology being developed clarifies the question.

1. What is the purpose of the technology being developed in your research? Write it with a few sentences.

Fig. 3. Writing research objective

Step 2: In the second step of this activity, the participants are asked to select a parameter from the 39 parameters of the TRIZ contradiction matrix (Fig.4) which they intend to improve through their research. They are also asked to select another parameter which becomes worse due to the improvement of the parameter they selected. This activity encourages the participants to notice a contradiction their research is trying to overcome.

2. Select a parameter which you are trying to improve through your research. Then, select another parameter which gets worse when you improve the above parameter

1, Weight of a moving object	14, Strength	27, Reliability
2, Weight of a stationary object	15, Time of action of a moving object	28, Measurement accuracy
3, Length of a moving object	16, Time of action by a stationary object	29, Manufacturing accuracy
4, Length of a stationary object	17, Temperature	30, Harmful factors acting on an object from outside
5, Area of a moving object	18, Brightness	31, Harmful factors developed by an object
6, Area of a stationary object	19, Energy spent by a moving object	32, Manufacturability
7, Volume of a moving object	20, Energy spent by a stationary object	33, Convenience of use
8, Volume of a stationary object	21, Power	34, Reparability
9, Speed	22, Loss of energy	35, Adaptability
10, Force	23, Loss of a substance	36, Device complexity
11, Tension/Pressure	24, Loss of information	37, Control complexity
12, Shape	25, Loss of time	38, Level of automation
13, Stability of composition	26, Amount of substance	39, Productivity

Fig. 4. Selecting from list of applicable parameters

Step 3: In the third and final step of this activity, the participants are asked to define the contradiction by using the technical words in their fields based on the parameters selected in the previous step. The participants states their contradictions by fillng the blanks in the sentences shown in Fig.5.

3. Fill the blanks to define the contradiction in your research with respect to the parameters you selected in the previous activity.
(Use technical words in your fields.)

In order to improve ______

→ ______ gets worse.

But

In order to improve ______

→ ______ gets worse.

Fig. 5. Defining contradictions

Activity 2: Defining key technical components

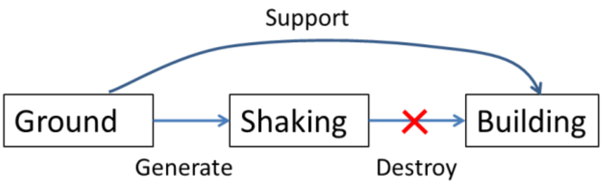
Simple function analysis was also introduced as a tool for defining the key technological components in the participants' research. Although this is used in TRIZ to find conflicts present in a technological system [5], the authors experimented with its use as a tool for the participants to check if any conflict exists in the way they present the key technical components in their paper. This activity is useful for the participants to organize the key components in their research with simple combinations of subject-verb-object.

First, participants were asked to illustrate and visualize the interaction of the key components in currently existing systems (Conventional System), as well as those included in the solutions proposed in their research (New System). Fig.6 shows a part of handout for the activity with a simple example of Earthquake proofing system for buildings.

List the components included in your research for both conventional system and new system which you are going to propose through your research.

Conventional system	New system
Ground	Ground
Building	Building
Shaking	Rubber bearing
	Shaking

Draw a function analysis model of the conventional system of your research.



Draw a function analysis model of conventional system of your research.

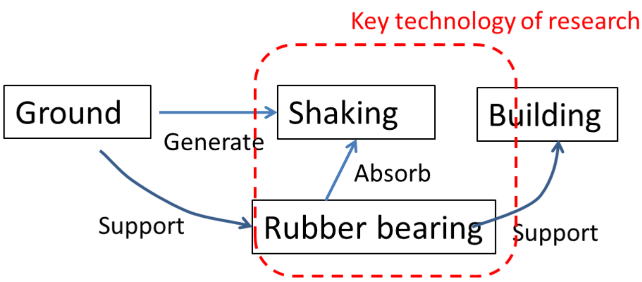


Fig. 6. Defining key technical components

4. Preliminary workshop and future work

A preliminary workshop using the method introduced above was implemented with 10 participants from the school of engineering. The students were from different fields of engineering. According to the questionnaire taken after the pilot activity, 7 in 10 participants answered they noticed new contradictions in their research through this activity. In addition, 8 in 10 realized that recognition of these contradictions facilitated a new clarity that would make it easier for them to communicate their research findings. At the end of the activity, all of the participants were able to define the contradictions and find the key components in their research. This was the initial goal of these workshops, and the authors' believe that this new method was successful in this regard.

In future workshops, the authors are going to develop more activities which utilize function analysis to encourage deeper exploration of the key components in order to promote correct, clear and concise communication of research.

5. Conclusion

The ability to communicate research work through effective academic writing is an important skill for university students to publish work in academic journals. In cases where students have little opportunity to adequately improve their English writing skills, a new strategy to support students' technical writing is needed. This paper demonstrated a new application of TRIZ as a tool for supporting clear definition of the student's research objective and the conclusion. The TRIZ concepts of solving contradiction based on the 39 parameters were used in organizing the multitude of information a student needs to sort during their research activities. Function analysis was also used to clarify the technical key point of participants' research. While this new method is still in initial development stage, the authors' received positive responses from participants of the preliminary workshop. This workshop served a strong motivation for the students to rethink their approach of communicating their research findings.

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APPLICATION OF TRIZ IN ADVANCED MANUFACTURING SYSTEM

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Abstract

This paper analyses the process which affect the production efficiency in the process of production process based on a company about the advanced manufacturing system. It uses conflict theories of TOC and TRIZ to confirm the existing conflicts in the optimization of advanced manufacturing systems. The aim of this paper is in search of ideal solutions based on the 40 principles of TRIZ and then confirms the optimization scheme of advanced manufacturing systems. So as to increase productivity, reduce costs and improve the competitiveness of enterprises.

Keywords: TRIZ; Advanced manufacturing system; TOC

1. Introduction

With the development of market economy and global economic integration, enterprises are confronted with fierce competition increasingly. Due to the rapid development of science and technology and increased competition in the market at home and abroad, enterprises pay more attention on the management of their manufacturing process and continue to explore effective process management to improve their competitiveness and viability. TRIZ and TOC theories provide a favorable solving idea to discover and solve conflicts in the process management of enterprises' advanced manufacturing system.

2. Advanced manufacturing system

Manufacturing industry is the pillar industry of the country, while manufacturing technology is necessary to support the manufacturing production, improve labor efficiency, reduce costs, meet environmentally friendly production and guarantee quality. It is also the source energy for the sustainable development of the national economy. Advanced manufacturing systems theory originated from the western developed countries which is the summary of their manufacturing production activities and management methodology. It's the achievements of modern science and technology , and also owing to the development of modern management theory.

AMS (Advanced Manufacturing System) refers to a manufacturing system which can well meet the market demands in the aspects of time, quality, cost, service and environment. It will get good social benefits through using advanced manufacturing technology, advanced manufacturing mode and coordinated operation.[1]

With the development of manufacturing technology many AMS are appeared, such as FMS (flexible Manufacturing Systems), CIMS（Computer Integrated Manufacturing System）, AM(Agile Manufacturing), LP(lean production), CE(Concurrent Engineering), IM(intelligent manufacturing), Reengineering, and so on. All of them have the same characteristics of flexibility, integration, intelligent and networked. Their common goals are to improve product quality and production efficiency, shorten design and manufacturing cycle, reduce production costs, furthest increase the resilience of the manufacturing sector towards the market and meet customer needs.

3. TRIZ and TOC

3.1 TRIZ

TRIZ (a Russian acronym) is a theory which means to solve the problem of invention and innovation. It is originated from the Soviet Union, and be translated in English as the Theory of Inventive Problem Solving which abbreviated as TIPS. Based on the world famous patent, G.S. Altshuller gets some principles of inventions to eliminate the conflict and establishes a knowledge-based logic method to eliminate conflicts. These methods contain 40 inventive principles, ARIZ (Algorithm for Inventive Problem Solving), 76 TRIZ standard Inventive Solutions, Substance-- Field analyses, the effect, and so on.

With the further research of TRIZ, its basic ideas and tools have been applied in the areas of process management. Companies tend to use TRIZ to analyze various problems in the production process and develop programs to improve the technical. However, they haven’t got a good effect because there are too many technologies improvement programs to identify the priority for the employees.

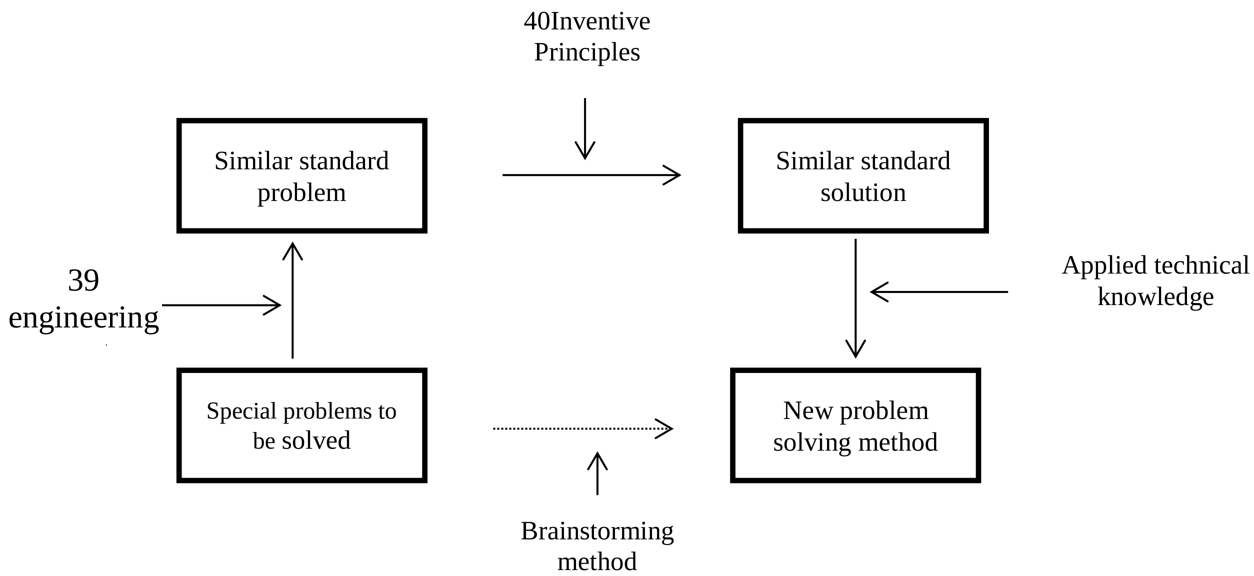


Fig 3.1. General methods of TRIZ to solve invention problem[2]

3.2 TOC

TOC is a collection of management philosophy and thinking tool which is originally originated from OPT Which first refers to optimized production timetables and then refers to optimized production technology. OPT was co-founded by Dr. Goldratt and other three Israelis. They brought it to American in the latter half of 1979 and then established Creative Output Company where the TOC has been known by people today ten years later. He first proposed the TOC in the book *The Goal* which published in 1984[3]. Wang Yurong, a TOC expert, made an in-depth and extensive research on this theory. She provided a relatively perfect definition for it that TOC is a set of advanced management concepts concerning how to improve and implement the improvement best.[4] TOC also developed a logical, systematic problem solving method--TP (thinking processes) while more people began to know it. TOC thinking Process includes CRT (current reality tree), CRD (contradiction resolution diagram), FRT (future reality tree), PT (prerequisite tree) and TT (transition Tree). These five logical charts are established on the basis of sufficient logic and necessary logic which guide designers to follow a five-steps solution of structural problems. The five-step solution is identify problems, establish the solution, decide obstacles that need to be solved and implement solutions. This paper will confirm the conflicts in the AMS with CRT and CRD.

CRT, which is established on sufficient logic, describes the reality of a given system. It reflects the causation chain of a given system under certain circumstances, and concludes the root cause from the obviously existing problem in the system. Current establishment of reality tree starts from “roots”, and develops to “trunk” and “branches” till “leaves”. “Roots” are the fundamental issues. “Trunk” and “branches” are intermediate results. “Leaves” are the final results. Current reality tree answers the first question raised by the system that what should be changed.

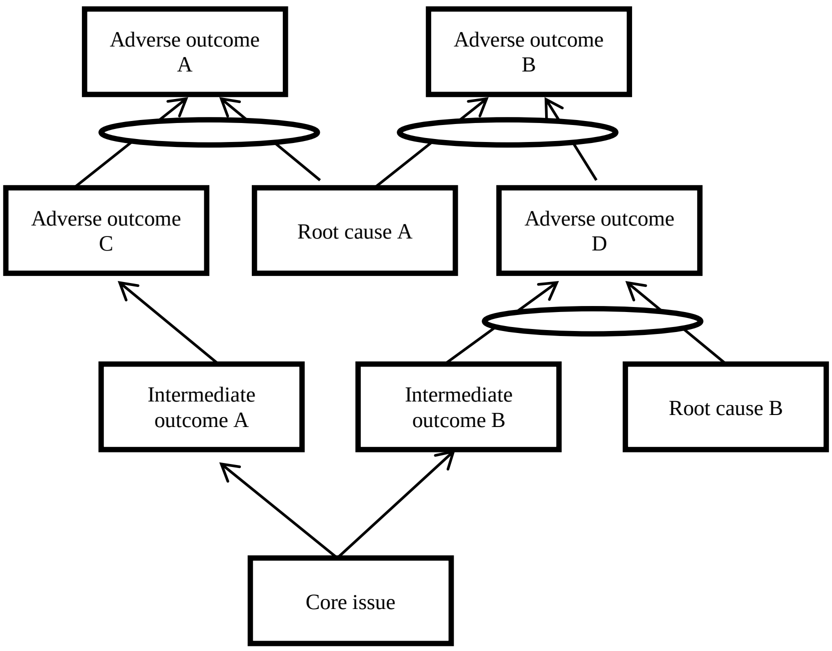


Fig 3.2. Structural draw of current reality tree[5]

CRD, also called "Steam Cloud", is established on the basis of necessary logic which can display all the elements in the environment and then determine the conflict and find solutions to solve problems. It can be used to determine the existence of a conflict, identify the main problems leading to the conflict, analyze reasons for problems, determine a win-win solution and confirm all settings existing between the problems and conflicts.

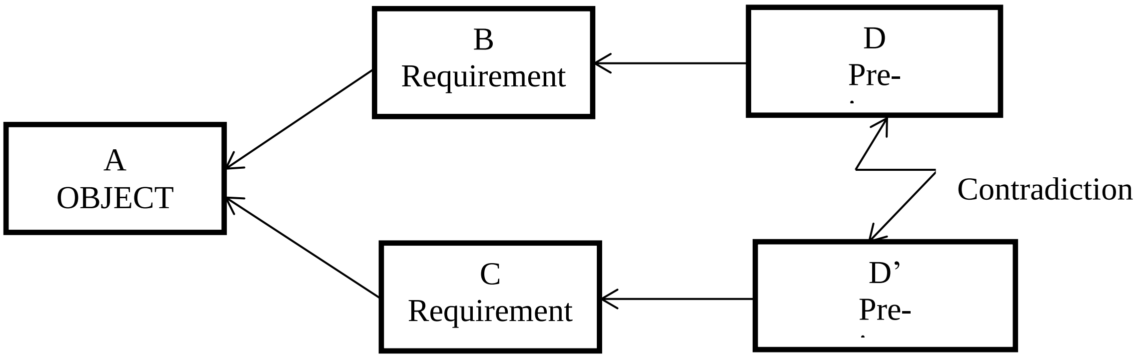


Fig 3.3. Conflict-resolving chart[6]

CRD, the "Steam Cloud", generally has a fixed expression format which including one objective, two basic requirements and two preconditions, as shown in Figure 3.3. In order to achieve the objectives A, it must have the basic requirements B; In order to achieve the objectives B, it must have the preconditions D. Meanwhile, in order to achieve the objectives A, it must have the basic requirements C. In order to achieve the objectives C, it must have the specific preconditions D'. There is a conflict between preconditions D and D', which causes the target A difficult to achieve. Generally speaking, the conflict between precondition D and D' is the bottlenecks that restrict the performance improvement of technology systems, therefore it should be studied as the primary object of technical contradiction.

TOC can be used as a process management method which on the basis of bottleneck capacity. The method, which breaks through the limitations of traditional process management, starts from breaking business process bottlenecks. Then it discovers and solves new constraint links to improve the entire system continually. TOC is an extremely effective theory which has a set of methods and practical tools for solving specific problems and technological conflicts. One of the most important contributions is to guide company to concentrate its limited resources on the most critical areas and maximize the efficiency of enterprises.[7] Many companies of the fortune 500such as 3M, Amazon, Boeing, Delta Airline, Ford Motor Company, GE, General Motors, Lucent Technologies and so on, applied TOC technology in their process management and had got significant improvements.

3.3 Design method for process improvement on the basis of TRIZ and TOC

Studies have shown that the CRT and CRD tools have played a prominent role in defining the key issue and identifying the contradiction in the process improvement. Based on the study achievements mentioned above, we build the process improvement plans according to TOC and TRIZ. There are five steps as shown in Figure 3.4.

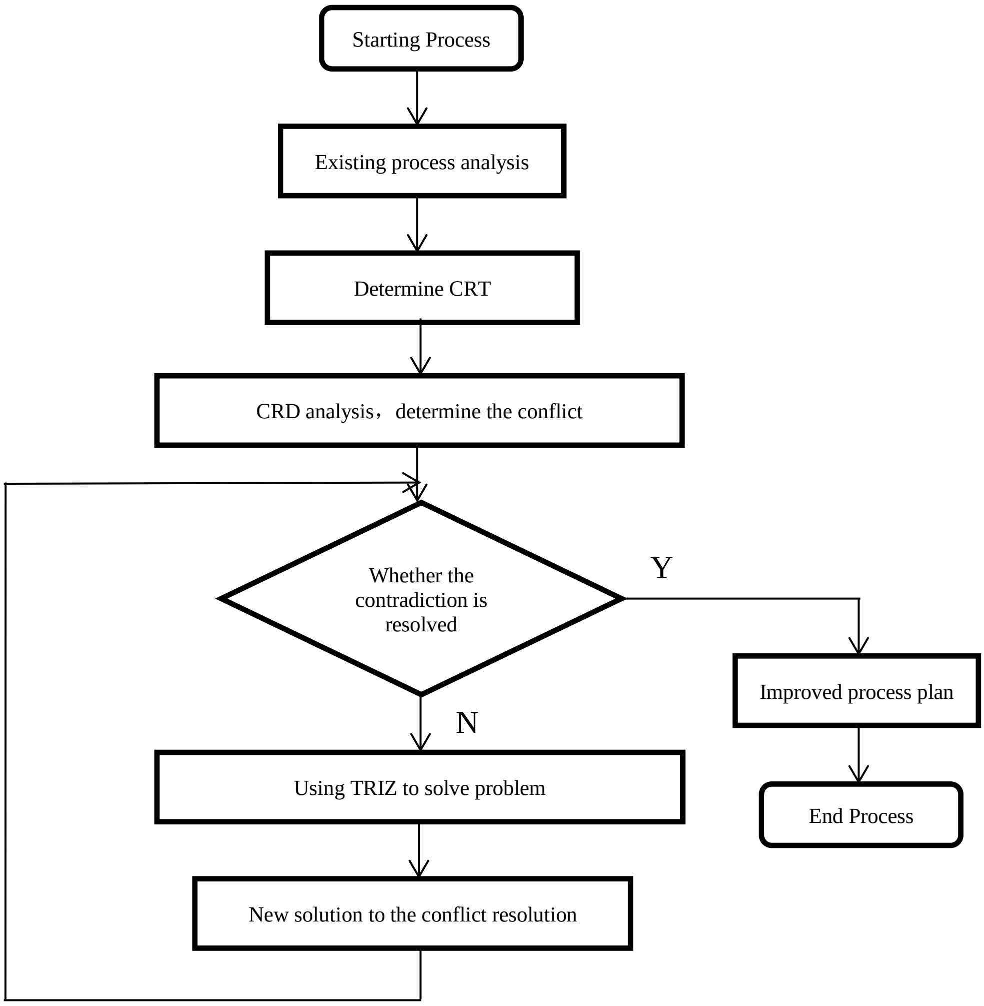


Fig 3.4. Process improvement plans on the basis of TOC and TRIZ

Step 1: Analyzing current situation of existing processes. Using CRT to draw the function tree of process. Setting up the function tree of current process.

Step 2: Building CRD of the process. Analyzing the basic requirements and preconditions of the process. Determining contradictions.

Step 3: Setting up process improvement program to solve contradictions. As for the contradiction concluded by the results of CRD analysis. Setting up the process improvement program if it can be solved by current technological tools. If it can't be solved, it will be considered by TRIZ to solve the contradiction creatively.

Step 4: Using contradiction analysis tool and method of TRIZ to get new contradiction solution. For all those unsolvable contradictions that proposed by CRD, repeating this step until all the contradictions are solved.

Step 5: Evaluating contradiction solutions and choosing the best process improvement.

4. Case analyses

4.1 Background

The case is about guard decrease and weight loss program of A type guard assemble process at the background of S company's advanced manufacturing systems during the process of lean production. The core idea of lean production is eliminating waste, streamlining the organization and continuous improvement. Its purpose is to getting maximum output with minimum investment by the way of improving technological to eliminate invalid labor and waste, cutting costs, and so on. The A type guard includes two parts: the left fender and the right fender, as shown in Figure 4.1. The left fender which is 84KG weight comprises a welding curved plate, decorative panels and left-sliding doors. The right fender with the weight of 102KG comprises a cabling channel, a curved welding plate, right-sliding doors, a CRT box and decorative panels. Such a large weight brings serious difficulties to assembly workers and also affects the efficiency of the assembly.

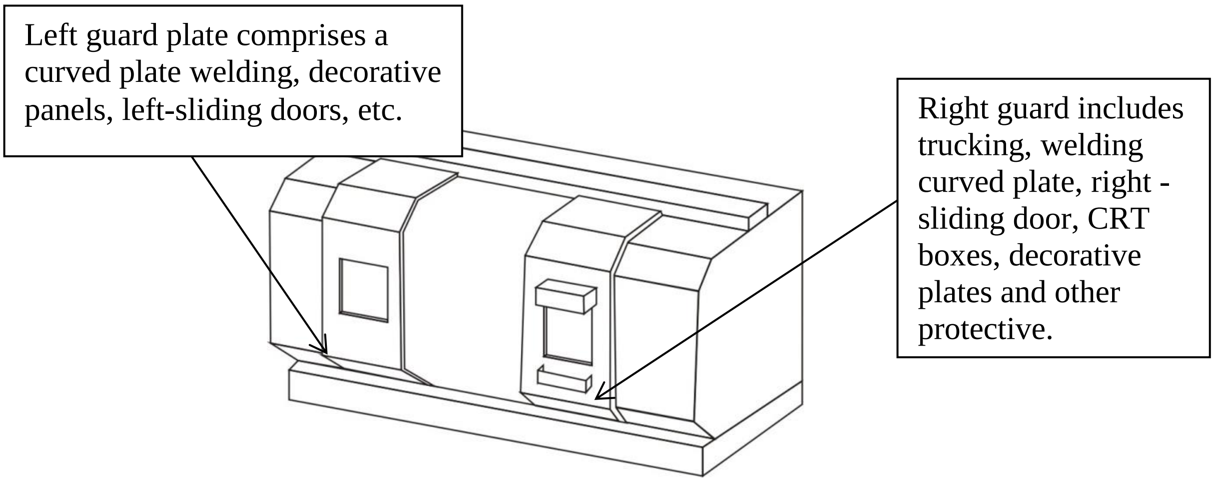


Fig 4.1. The current situation of A type guard assembly

4.2 Conflicts Analysis of existing process improvement

Through the assembly process analysis of A type guard, we can see that two basic requirements must be satisfied if we want to make fenders easy to assemble and maintained to improve assembly efficiency: B and C must be filled. That is to say, the fender must be light but also maintain a certain strength and weight in order to work properly. In order to fulfill these two basic requirements, there are two preconditions must be satisfied: D and D'. But D and D' conditions have a conflict about reducing the weight of components which is shown in Fig4.2. In order to figure out the nature of the conflict, We need to describe and analyze the existing conflict in CRD sufficiently and then use effective tools to resolve the conflict. The descriptions of CRD are as follows:

(1) In order to achieve A condition, B condition is necessary. In order to achieve the basic requirement that reducing fenders' weight, the precondition of D condition must be achieved.
(2) In order to achieve A condition, C condition is necessary. In order to achieve the basic requirement C condition, the precondition of D' must be achieved.

(3) On the one hand it needs D condition, on the other hand it needs D’. These two requirements are mutually exclusive for they cannot be achieved at the same time. So there is a physical conflict between them.
(4) D condition harms C condition.
(5) D’ condition harms A condition.

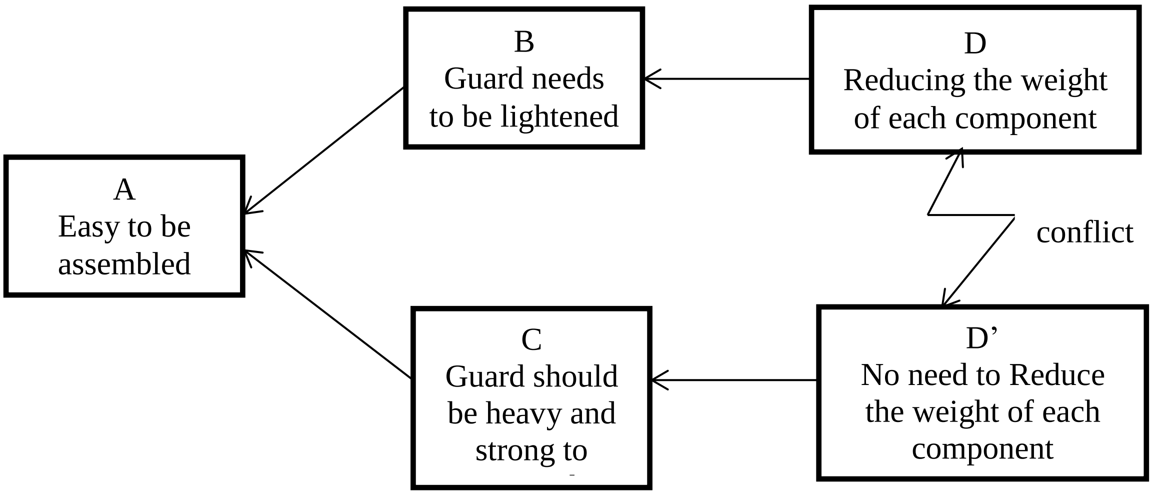


Fig 4.2. CRD analysis of A type guard

4.3 Using TRIZ to analyze and resolve the conflict

As shown in fig 4.2, there is a technical conflict between B condition and C condition, and also a physical conflict between D condition and D’ condition. The Conflict Matrix of TRIZ may solve the conflict existing in the process of CAD. We may use some of the 39 engineering parameters to describe this phenomenon. These parameters are No.13-structure stability and No.14-trength. Using these two engineering parameters in conflict matrix of TRIZ , we can get two recommended inventive, principle 5 and principle 6. As shown in Table 4.1.

Table 4.1 Analysis of the conflict and solving principle

The main conflicts which are determined by CRD	D Reducing the weight of each component	D′ No need to Reduce the weight of each component
Standard engineering parameters Description Conflict	No.13Structural stability (guard needs to maintain a structural integrity)	No.14 Strength (guard needs To resist external force and protect the internal structure)
Invention Principle	No.5，No.6	
Solve problems using the Invention Principle	No.5: Combining Principle. Similar objects in space will be linked together to perform parallel operations. No6: Multi-functionality Principle. Making an object or system perform multiple functions so as to eliminate the need for other parts.	

4.3 Using TRIZ inventive principle to design improvement plan

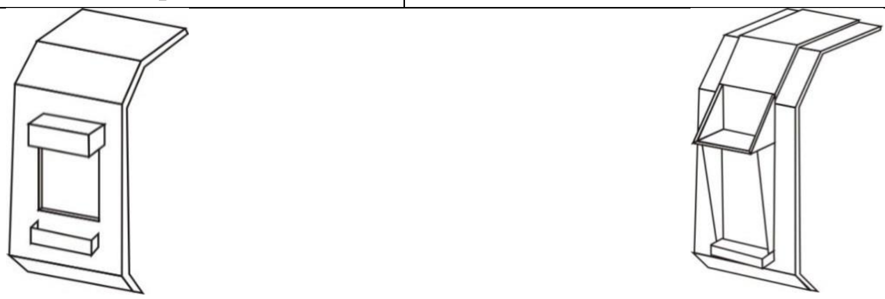
On the premise of guarantee the strength and the original function, we use inventive principle 5 and 6 to combine different parts and to implement integrated design. As shown in Figure 4.3 and Table 4.2: the left fender combines the decorative panels with the curved plate and left-sliding doors. It reduces its weight from 84KG to 68KG. As shown in Figure 4.4 and Table 4.3, the right fender combines the curved plate with the CRT boxes, decorative panels, and the right-sliding doors. Four parts are combined into one. The weight changed from 102KG to 87KG by reducing the stiffener and using hollow out design. In the practical application, this modified plan has a good effect on shortening the assembling period and quality improving.

The original weight is 84 kg The modified weight is 68kg

Fig 4.3. Comparison of left fender before and after the improvement

Table 4.2 Comparison of left fender before and after the improvement

Parts before the improvement	Parts after the improvement
curved plate	left-sliding doors
left-sliding doors	
decorative panels	



The original weight is 102kg The modified weight is 87kg

Fig 4.4. Comparison of right fender before and after the improvement

Table 4.3 Comparison of right fender before and after the improvement

Parts before the improvement	Parts after the improvement
curved plate	right-sliding doors
right-sliding doors	
CRT box	
decorative panels	

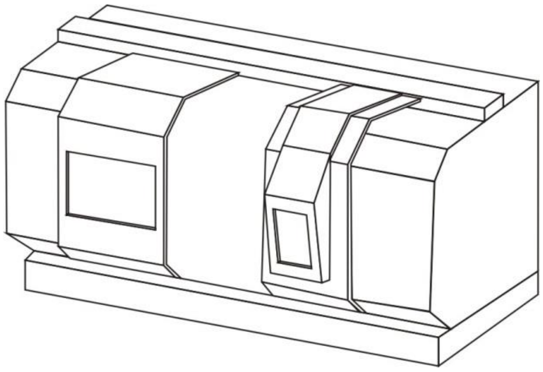


Fig 4.5.A type guard after improvement

5. Conclusion

Innovation is one of the key factors for a company to win in competition. Both TOC and TRIZ are theoretical methods and tools for practical problem solving, which can guide companies to use various resources rationally and to solve the key problem in the process of process management and improvement. It also enables company to use the shortest time and the minimum investment for the maximum return. TOC can guide company find the bottleneck problems and conflicts in the process of process improvement while TRIZ can provide various methods and tools to break bottleneck and to solve conflicts. Combining TOC with TRIZ in process management can effectively improve the process management of the enterprise, so as to create more benefit for the enterprise.

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APPLICATION OF TRIZ TO THE EVOLUTION AND DEVELOPMENT OF SYSTEMS ENGINEERING PROCESS MODELS

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Abstract

It is the core question that what model is utilized to describe and represent systems engineering process. After analyzing the advantages and disadvantages of classical Hall's systems engineering model and the evolution of systems engineering process models from TRIZ perspective, this paper proposes the PERA three-dimensional lean R&D systems engineering abstract model framework based on the enhancements and extensions to Hall's systems engineering model. The application of the proposed abstract model framework and its instantiation are also discussed from TRIZ perspective.

Keywords: TRIZ, systems engineering, process model

1. Introduction

For quite some time, people have made the mistake of thinking product design activities occur only in the early stages of the product life cycle, such as conceptual design and detailed design; manufacturing activities occur only in the mid-stage of the product life cycle, i.e. manufacturing and production phases. However, the reality is that the design and manufacturing activities, especially design activities, can take place throughout the entire product life cycle, not just a stage of it. The reason for the misunderstanding is the confusion between the artifacts' cradle-to-grave maturity growing up process and the problem solving thinking process of all stakeholders of the product life cycle, and the simplistic view of the product life cycle as one-dimensional linear sequential activities along time-axis.

In fact, as early as in the 1960s, along with systems engineering in the successful practice of many major projects, the industry and academia of the United States summed up the systems engineering practice and proposed later well-known Hard System Methodology which has several important indicators: Arthur D. Hall published the book "A Methodology for Systems Engineering" in 1962; then he proposed a three-dimensional morphological model[1] for systems engineering in 1969; finally the systems engineering standard based on the Hall Model, MIL-STD-499A, was released in 1974.

In TRIZCON2009 the author[2] proposed an enhancement to Hall's model and introduced DIKW (data-information-knowledge-wisdom) hierarchy into the knowledge dimension in order to analyzes Computer Aided Innovation process and identify the interactions among R&D staff, technical systems, and the cognition results of the product life cycle from the systems engineering perspective. This paper continues to propose a new three-dimensional systems engineering framework based on Hall's model and analyzes the evolution of systems engineering process models from TRIZ perspective.

2. Traditional Systems Engineering Process Model by A. D. Hall

Hall's model (see Fig. 1) emphasizes the need of regarding systems engineering as a practical program of problem solving and separate the system life cycle stages and problem solving logical steps into two dimensions with morphological analysis, therefore the above misconception is clarified and eliminated. The knowledge dimension of Hall's model lists eight professions following the decreasing order of the degree of formal or mathematical structure. These professions are the application areas of the two-dimensional systems engineering activities matrix consisting of the logic dimension and the time dimension.[1]

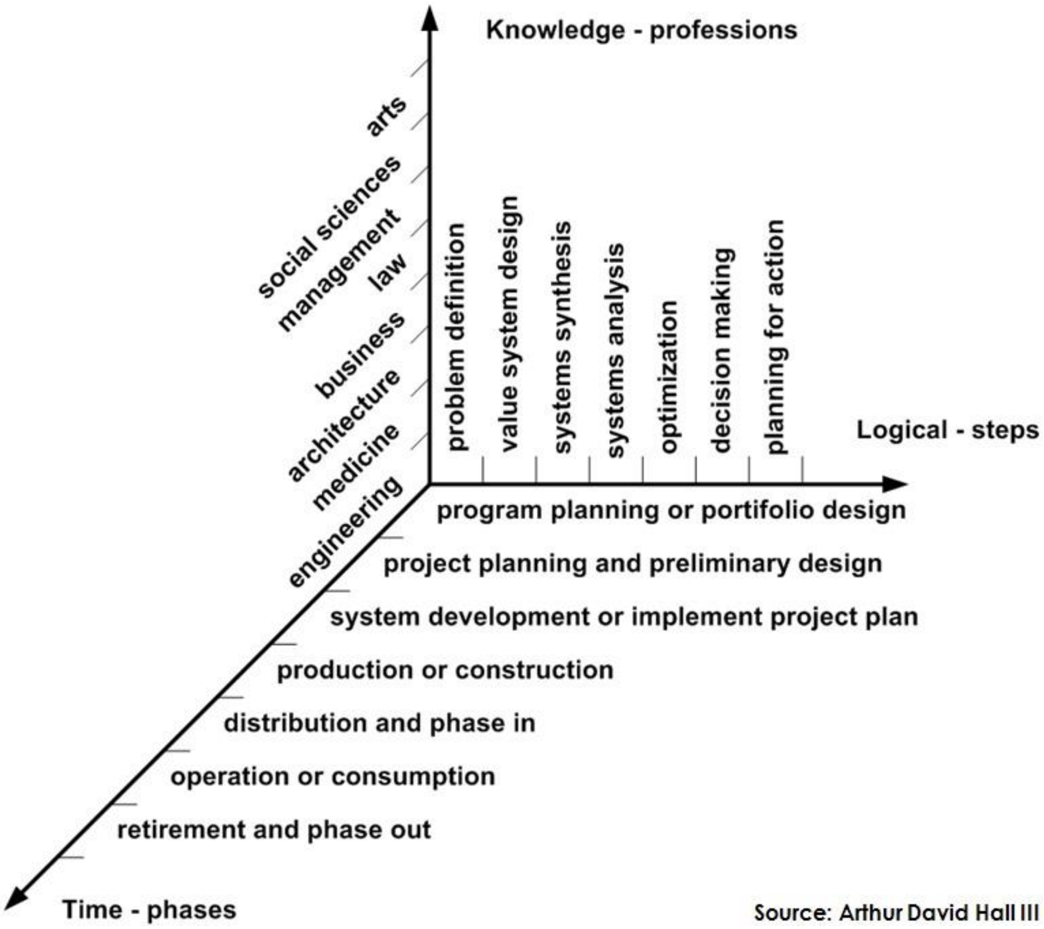

Fig. 1. Three-dimensional morphological model for systems engineering[1]

The biggest advantage of Hall's model is the strictly separated thinking about systems engineering process with the dimension of problem solving by individuals and organizations (i.e. the logic dimension) and the dimension of artifact systems maturity growing up (i.e. the time dimension). That means the one-dimensional linear product R&D process is added with a new dimension and becomes a two-dimensional plane. The No. 17 inventive principle of TRIZ, Change Over to Another Dimension, says that adding a new dimension means a brand new perspective or totally change of viewpoint to the problem or system-of-interest, and new available space resources or characteristics and emerging opportunities for problem solving or systems value adding. The new added dimension is not from nowhere, but a response to the progresses of sci-tech in the middle of last century that expands human being's ability to know and transform nature and presents new challenges to handle the complex systems R&D and operation.

As the evolution of a technical system, the evolution of the system of product R&D processes and PLM processes models should be consistent with the Trends of Technical Systems Evolution in TRIZ. For example, When the Trend of Harmonization of Rhythms is applied to the system, it means that the understanding and abstraction of product R&D and PLM processes tend to harmonize rhythms of their components (i.e. the models) and with their supersystems (i.e. the engineering practice of product R&D and PLM, enterprise R&D system development, and the environment of new sci-tech and industry revolution) during evolution. The morphological analysis in Hall's model transforms the systems engineering process model from one-dimensional to two-dimensional, and then to three-dimensional. It exactly reflects the Line of Geometric Shapes Evolution (point->Line->surface->body) under the Trend of Harmonization of Rhythms, coordinating the interactions between the subsystem of R&D staff problem solving thinking process model and the subsystem of artifact systems maturity evolution model, as well as between the system and the supersystem environment.

The biggest problem of Hall's model lies in its knowledge dimension. For example, most Chinese interpretation of this dimension is a list of arbitrary disciplines and completely changes its original meaning, therefore the arrows of this dimension loses both its business meaning and model inherent characteristics, such as abstract, seriousness and universality. Furthermore the position and role of the three dimensions of Hall's model are different, the logic dimension and the time dimension which form the two-dimensional systems engineering activities matrix are the foundation of Hall's model, and the various professions or disciplines in the knowledge dimension are only certain application areas of the matrix.

Even the arrow of knowledge dimension of the original Hall's model is meaningful and the three dimensions can be detailed with more professions, subdivide phases and steps respectively according to user's own viewpoint, whatever a profession in the knowledge dimension is whether an application of the matrix or the collection of knowledge and technologies supporting to complete systems engineering process, a point in Hall's model three-dimensional space can only be a guide of a phase and a step applied to a profession or a certain knowledge subject areas in textbooks, whose forms are only paper-based or electronic documents. It greatly reduces instructive and practical operation value of the knowledge dimension comparing to the other two dimensions. It means that although traditional systems engineering approach represented by Hall's model was successful in aerospace and defense industries in the United States, western Europe, and China in the last century, it has been facing enormous challenges since the turn of the century and nowadays. The rapid development of information technology has greatly increased the complexity of the various artificial systems, revolutionized human warfare patterns and lifestyles. Document-centric Hall's model and traditional systems engineering approach is not able to handle the complexity anymore.

Facing these challenges (demand-pull and technology push), as the approach applying systems thinking, principles and methods to solve complex problems and ensure that people do the right things and do complex things right, systems engineering must change with the times and demands, abandon the outdatedness of traditional methods, create new paradigms, and transform Hall's model to the next level in accordance with the Trends and Lines of Technical Systems Evolution towards the re-coordination with the supersystem environment of new sci-tech and industry revolution. Many advanced technologies pilot projects in EU and the United States are moving such a coordinated effort to match projects propose and demonstrate a new model-based paradigm. In the new paradigm most errors are nipped in the bud, there is no rework, most of the physical test is replaced with digitized simulation instead. And its R&D efficiency increases dozens of times more than traditional systems engineering approach.

Why does the new model-based paradigm have so much power and potential to transform Hall's model to next step of evolutionary transition and break the impasse of complexity? It is necessary to analyze not only the shortcomings of Hall's model, but also the defects of document-centric paradigm and the new features of model-based paradigm, and then propose the enhancements to Hall's model.

3. New 3D Framework of Systems Engineering Process Model by PERA

In the 1990s the popularity of the PC and the application of office software achieve the transition from paper-based documents to electronic ones and facilitate document storage, copy and modification, but those inherent defects of the document-centric paradigm, such as semantic ambiguity, static property of text representation, non-association between documents, has not been changed. For the dynamic management of thousands of requirements and 100,000 of the interfaces between subsystems and components, document-centric paradigm is still powerless.

IT tools, especially CAx tools, greatly improve R&D efficiency only for specific domains. The interactions between professional domains, subsystems, the phases are still document-centric and based on the throw-over-the-wall mode. Due to the lack of information modeling and collaboration means to support complex products and systems decomposition and transformation from requirements into functions, to track the changes of requirements and designs, to quantitatively represent the interfaces and design solutions involving multidisciplinary and system elements interactions with the exponential growth, trade-off and optimization, communication and decision making, verification and validation (V&V) of designs solutions to stakeholder requirements, the document-centric mode results in a large amount of quality problems and hidden troubles needing tinkering and reinventing the wheel during verification, integration and operation stages.

At the turn of the century, with the emerging and application of SysML, STEP, Modelica, FMI (Functional Mock-up Interface), etc. a series of information modeling, system modeling, system simulation standards and MBSE, PLM tools and platforms, systems engineering starts its transformation from document-centric paradigm to model-based paradigm to overcome above shortcomings because of the consistency, traceability, verifiability, dynamic relevance along the entire life cycle of the model. Then the fence grid resulting from Hall's model two-dimensional systems engineering activities matrix and the throw-over-the-wall R&D mode is expanded to a 3D collaborative space across the entire system life cycle, all systems engineering technical processes and enterprise intellectual assets whole value chain.

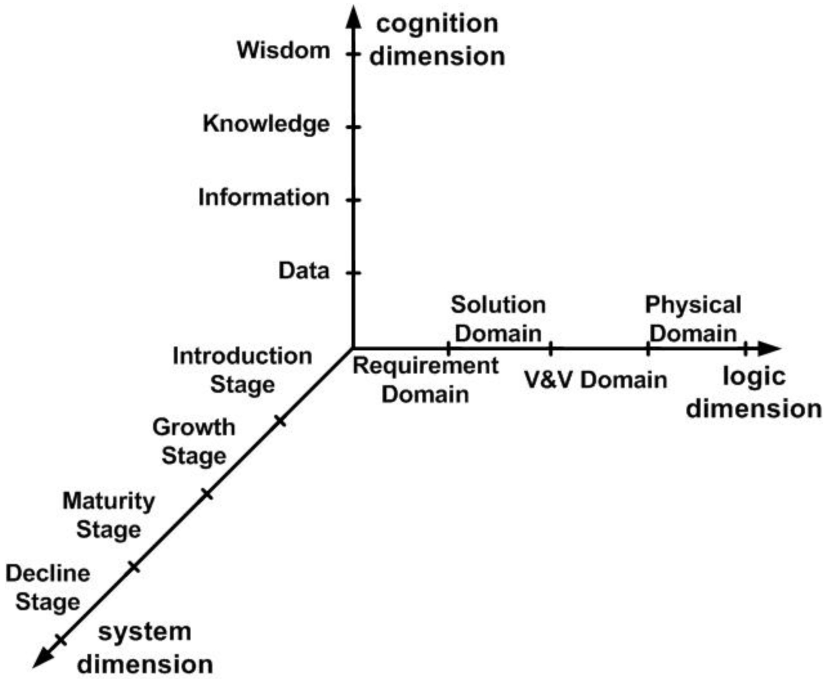

Fig. 2. PERA three-dimensional lean R&D systems engineering abstract model framework

In order to cope with the transformation of systems engineering, by applying the Change-Over-to-Another-Dimension inventive principle and Line of Geometric Shapes Evolution, the author makes certain modifications, extensions and abstractions to Hall's model, including changing the name of knowledge dimension to cognition dimension, time dimension to system dimension, introducing DIKW hierarchy into the knowledge dimension, introducing the meaning of time into all three dimensions, so that the arrows of all three dimensions have actual business meaning, and propose the PERA three-dimensional lean R&D systems engineering abstract model framework (see Fig. 2), details as follows.

(1) The replacement of knowledge dimension by cognition dimension.

This change adds new business meaning and value to the third dimension of Hall's model. The DIKW cognition dimension represents the value-added order of the intellectual hierarchy of individuals and organizations, reflects the cognitive processes of subjective world transforming the objective world, including both the generation, conversion, transition and management of DIKW during artifact systems life-cycle and the application of existing DIKW within the organization to the artifact systems life-cycle, which cover both the application scenarios of original Hall's model knowledge dimension and the Chinese misinterpretation of this dimension. Therefore, the paper- and document- based knowledge dimension of Hall's model becomes a plane in the cognition dimension of the new model. The new cognition dimension can record the cognitive processes and results of the subjective world understanding and transforming the objective world. With deepening the understanding of individuals and organizations to artifact systems, the accumulated cognition flow (data->information->knowledge->wisdom) is exactly the subject of enterprise R&D capability development system. The new cognition dimension is the dimension of matter and business. The IT platforms of PDM/PLM, knowledge management/knowledge engineering, technology management belong to this dimension. This new dimension responses the latest progress of sci-tech and industry revolution such as industry 4.0 and the deep integration of industrialization and informationization promoted by the China government with the support and promotion of industrialization by new IT such as big data, cloud computing, IoT etc., deal with the increasing complexity challenges of large scale cyber-physical system, and introduce the R&D organization capability development and its maturity growing-up process into the system of complex products and systems R&D.

When reviewing this change from other Trends of Technical Systems Evolution perspective, we can obtain more useful enlightenment. For example, from the Trend of System Completeness and the Trend of Energy Conductivity point of view, the DIKW cognition dimension supplement the system of product R&D processes and PLM processes models with the Control Unit and the Measurement Unit, and support the representation and implementation of eight technical management processes (i.e. project planning, project assessment and control, decision management, risk management, configuration management, information management, measurement, and quality assurance) and six organizational project-enabling processes (i.e. life cycle model management, infrastructure management, portfolio management, human resource management, quality management, and knowledge management) of systems engineering[4]. The working media of traditional systems engineering process based on Hall's model is the document which cannot play the Control Function and the Measurement Function on the systems engineering process and need full involvement of people. Under the new paradigm based on the PERA three-dimensional lean R&D systems engineering abstract model framework, model is the new working media with much less involvement of people, reworking is substantially reduced and communication efficiency and effectiveness become much higher and thus the information/energy transmission loss is significantly reduced. The system of product R&D processes and PLM processes models can perform part of Control Function and Measurement Function with its own components. In order to further improve the information/energy transfer efficiency, reduce the loss of communication of interdisciplinary models, format conversion, interoperable information/energy conversion, the efforts of utilizing one single form of information/energy field across the entire product life-cycle and systems engineering processes are emerging, such as STEP/PLCS standards, ontology engineering, architecture-centric model management, product data collaboration center and model bus, etc. The fact of reducing human involvement and changing the working media of systems engineering process from document to model also fits the Line of Replacing Difficult Controlled Field with an Easily Controlled One.

(2) Rename time dimension with system dimension.

The new system dimension focuses on the evolution of artifact systems (such as technologies and products which are objects being understood and transformed by the subjective world) with maturity growing up. The new system dimension is the dimension of objects.

(3) Abstract original seven steps in the old logical dimension into four domains, i.e. requirement (or problem), solution, verification and validation, and physical domain.

The new logic dimension describes the problem solving thinking process of the subjective world based on the systems engineering technical processes. The new logic dimension is the dimension of human thinking. CAx applications and other IT tools are the extension of the abilities of human and organizational thinking and problem solving.

(4) The PERA three-dimensional lean R&D Systems Engineering abstract model framework can be customized and instantiated according to the fractal and classified characteristics of the three dimensions and then provide human-objects-matters systems engineering model framework to specific business scenarios.

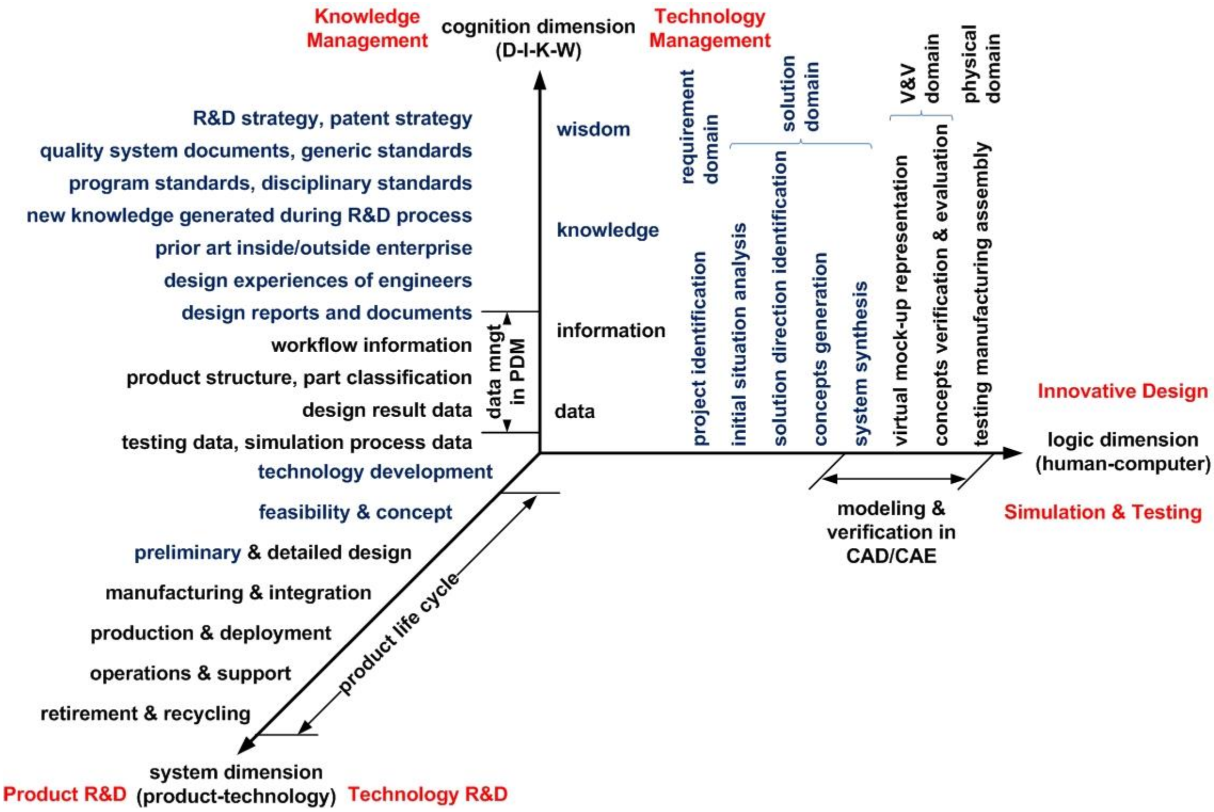

Fig.3. a PERA three-dimensional lean R&D systems engineering model instance

The four abstract system life cycle stages in the system dimension can be customized and instantiated to different system hierarchy level, such as system-of-systems, system, subsystem, and components, etc. and different R&D scenarios, such as technology R&D, product R&D, or both technology R&D and product R&D (see Fig. 3), and even architectural design and intelligent city planning and design.

In the logic dimension, it is the core question that what model is utilized to describe and represent systems engineering technical process. The waterfall model (by Dr. Win Royce, 1969), the spiral model (by Dr. Barry Boehm, 1983), Vee model (late 1980s), the feedback model (in Systems Engineering Management Guide, DSMC, 1990), the elliptical model (in MIL-STD- 499B, 1994), the circulation models (by Walter Hammond, 1999), the dual Vee model (by Kevin Forsberg and Harold Mooz, 2006)[5], as well as TRIZ inventive problem solving processes are all problem solving instance models in the logic dimension. The Vee model has a milestone significance. It is not just a bent waterfall model or serial development process. According to the Change-Over-to-Another-Dimension inventive principle, adding a new dimension means a brand new perspective to the problem or system-of-interest. The shape of Vee provides an accurate representation of the thinking process evolution from system decomposition to system integration and visualizes the systems engineering technical process, which makes it easy to manage.

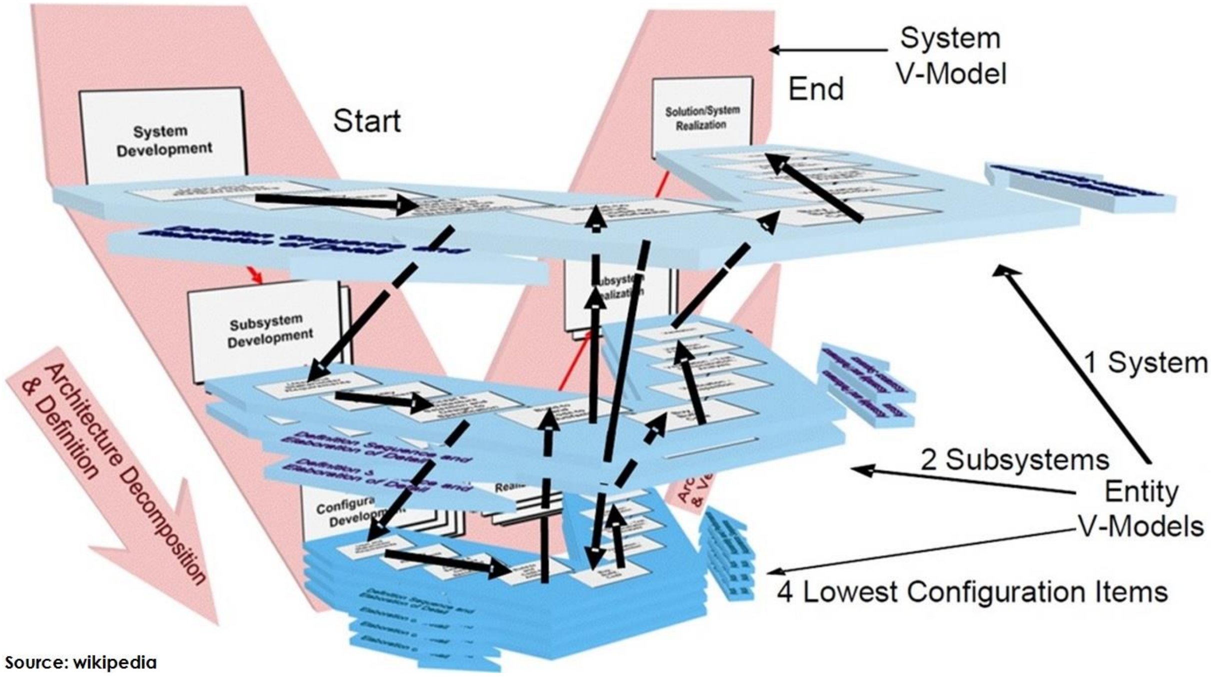

Fig.4. Architecture and entity Vees intersecting in dual Vee model[5]

The evolution of systems engineering process model from the MIL-STD-499B elliptical model to 2D Vee model and then to 3D dual Vee model with the consideration of concurrent development of system architecture and system elements entities reflects the Trend of Transition to Super-system of TRIZ, which makes the systems engineering process model to achieve quite a high maturity level. Besides the recursive application of the architecture Vee and entity Vees in along different system levels (see Fig. 4), dual Vee model can be customized and instantiated to those system characteristics, such as reliability, safety, supportability, etc., to those R&D scenarios, such as new product design, existing product improvement, failure diagnosis and troubleshooting, and to those software development mode, such as evolutionary development and incremental development.

In the cognition dimension, DIKW framework, methods and tools can be applied by different levels of the organizational structure, eight technical management processes and six organizational project-enabling processes of systems engineering mentioned above, and DIKW integration, analysis, mining, visualization scenarios such as engineering massive data, industry big data, internet big data, product model information management and collaboration, knowledge management, knowledge engineering, business intelligence and so on.

(5) The Measurement Units of PERA three-dimensional lean R&D systems engineering model instances are those capability maturity models for the three dimensions. CMMI is the enterprise process capability assessment model, in which the technology processes can be applied to upgrade the logic dimension capability maturity and technical management processes can be used to enhance the cognition dimension capability maturity. People-CMMI is the individuals/organization capability maturity evaluation model, which can be applied to upgrade human resource management capability maturity in the cognition dimension. TRL (Technology Readiness Level), IRL (Integration Readiness Level), SRL (System Readiness Level), and MRL (Manufacturing Readiness Level) are technology and product capability maturity evaluation model instances in the system dimension.

(6) Deeper application of the PERA three-dimensional lean R&D systems engineering model framework and instances is to analyze the interaction details between each two dimensions,

especially between the cognition dimension and the system dimension and between the cognition dimension and the logic dimension, and thus providing input for specific scenarios three-dimensional space modeling of business requirements and business logic.

4. Conclusions

After analyzing the advantages and disadvantages of classical Hall's systems engineering model and the evolution of systems engineering process models from TRIZ perspective, this paper proposes the PERA three-dimensional lean R&D systems engineering abstract model framework based on the enhancements and extensions to Hall's systems engineering model. The application of the proposed abstract model framework and its instantiation are also discussed from TRIZ perspective.

TRIZ and Systems Engineering share certain inherent consistencies because the two methodologies focus on problem solving both. They could complement each other very well. Each methodology should earn benefits when being reviewed from the other perspective. It is necessary to increase the communication and share inspiration between the two communities.

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COMBINING HIDDEN CUSTOMER NEED TOOLS AND MPV TO GENERATE PRODUCT CONCEPT

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Abstract

TRIZ is already very sophisticatedly developed in solving technical problems. However, more and more companies and researchers are exploring how to use TRIZ to develop product concept. There are few research results in this area. This article explores the principles and practices about how to use hidden customer need tools to identify and evaluate MPVs (Main Parameters of Value), how to generate product concept using TRIZ tools. More specifically, this article reveals how TRIZ tools could be combined with Repertory Grid and ethnography to identify and evaluate potential MPVs, how we could combine these tools to generate ideas and concepts. This initial research implies new opportunities in discovering new product concepts, which extend the applicability of TRIZ.

Keywords: TRIZ; Hidden Customer Need; MPV; Facilitation; Concept Development.

1. Introduction

TRIZ is already very sophisticatedly developed in solving technical problems. The traditional application field of TRIZ is technical problems, and the commonly used tools include problem analysis tools, problem modeling tools and problem solving tools, resting mainly on the concepts of ideality and contradiction [1, 2].

In recent years, TRIZ practitioners were more and more involved in developing brand new products, which is not only about the technical problem solving, but also about the product concept development. While product concept is related with technology, it's far more than just technology. TRIZ experts have used the so called "opportunity identification" tools to generate new product ideas and concepts. Some of the commonly used tools include Engineering Evolution Trends, Problem Hierarchy, Ideal Final Result, and 9/12 Windows analysis, etc. All these tools are related with the engineering system itself, but the development of product concepts rely heavily on understanding market trends and customer needs.

Few TRIZ tools address customer needs up to date. Main Parameter of Value (MPV) is one of them. Main Parameter of Value is a description of the parameter(s) that contribute most to Customer Value. However, there are several issues related with MPV. Firstly, there is no consensus about how to define MPV for a certain product, and different people could list different MPVs; Secondly, how does MPV link to problem solving or product concept development is not clear. This article suggested a thinking process and an algorithm to generate product concept based on customer perceived value, functionality and MPVs.

2. Main Function, MPV and Kano model.

Main function defines the main useful function of an engineering system, the main purpose why this engineering exists, for example, the main function of a car is to move people, and the main function of a fan is to blow air. Based on these, people easily assume that the parameters for main function is also the MPV. For example, parameters of a fan that are related with effectiveness of blowing air, such as power, shape of blade, etc., should be the MPVs. However, MPV is not the same with the parameter for the main function. By definition, MPV is the parameter (s) that create customer satisfaction and plays an important role in customer purchase decision. There is an inherent issue regarding MPV. As the products are mainly in competitive market, if the MPV is fulfilled and accepted, then the competitors will follow up, and the MPV will be just a basic parameter. For example, Volvo launched the vision of zero accidents on Volvo cars, which means they choose 100% safety as a MPV. If this proves to be an effective MPV, all other automobile manufacturers will follow up, and when all competitors achieve this target it won’t be MPV anymore.

So, there is no clear-cut criteria for determining MPV, and sometimes MPV is not obvious. It’s changing along the time. In the S-Curve, MPV is a little different in different stages. As shown in the below figure, MPV is increasing along with time in Stage I & Stage II. However, in Stage III and Stage IV, the MPV increases very slowly and even decrease. This implies that MPV is not where customers pay a lot of intention anymore. In other words, in Stage III and Stage IV the current MPV is not that important anymore.

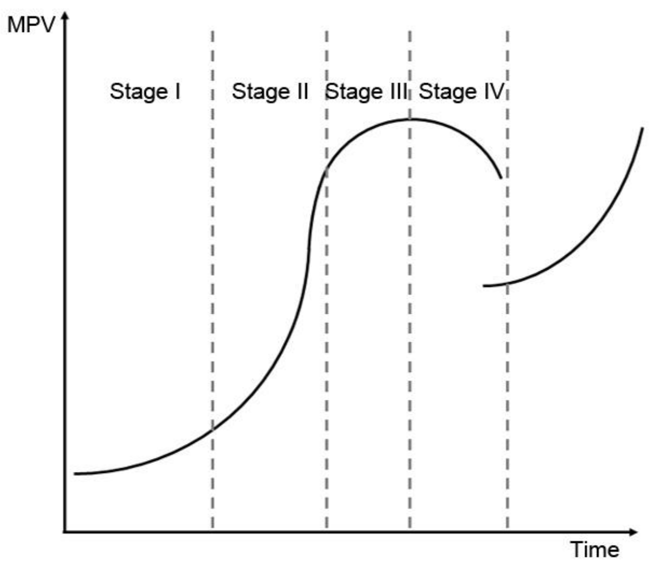

Fig. 1. S-Curve and MPV

How should we determine the MPV? As MPV is the main parameters that determines the values for customer, Kano model may provide some hint. Kano model is a tool about customer satisfaction developed in the 1980s by Professor Noriaki Kano [3], which classifies customer preferences into different categories based on how they are perceived by customers and their effect on customer satisfaction. The main three types of customer preferences include Basic, Performance and Excitement. Basic attributes are the expected attributes or “musts” of a product, and do not provide an opportunity for product differentiation. Performance attributes are those for which more is generally better, and will improve customer satisfaction.

Conversely, an absent or weak performance attribute reduces customer satisfaction. Excitement attributes are unspoken and unexpected by customers but can result in high levels of customer satisfaction, however their absence does not lead to dissatisfaction. Excitement attributes often satisfy latent needs – real needs of which customers are currently unaware.

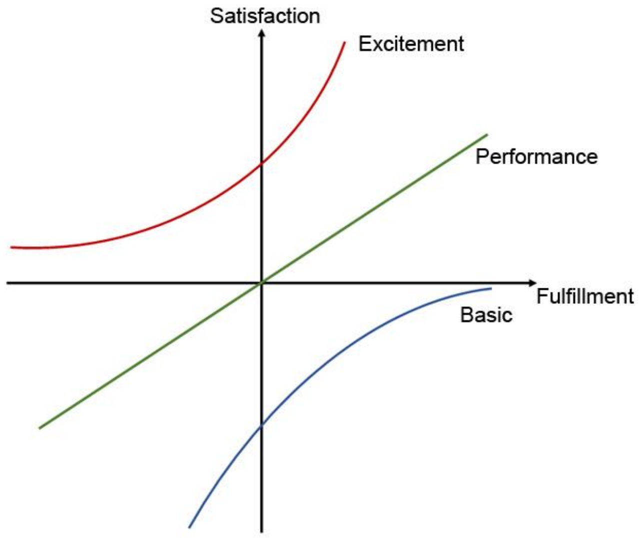

Fig. 2. Kano Model

Source: Noriaki Kano, 1984[3]

Professor Noriaki suggested to focus on performance attributes and excitement attributes. For performance attributes, we should outcompete among the market players. And we should identify excitement attributes that others don't pay attention to.

In general, as shown on the below figure, along with time, the excitement attributes will gradually turn to performance attributes, and then to basic attributes [4]. Imagine if we focus on improving the MPV of a product and it's a performance attribute, and along with the competition, the MPV changes from performance attribute to basic attribute, which means however we improve MPV, the level of customer satisfaction will not change. For example, right now, as voice recognition is applied in vehicle navigation system, the accuracy in voice recognition is one of the MPV, but when the accuracy is more than 95%, consumers are not that keen to the accuracy, so accuracy is no longer a MPV because it becomes a basic attribute.

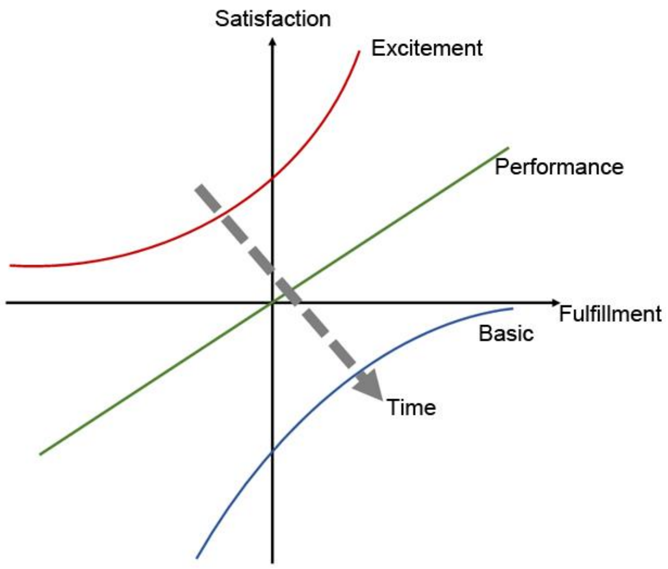

Fig. 3. Kano Model: Changes over time

Source: Zultner, R. E, 2006 [4]

3. Perceived Value-Function-Parameter

By definition, MPV means the parameters that create value and leads to customer satisfaction. In the field of marketing psychology, there is a term called perceived value. Perceived value is the collection of benefits that customer/consumer gets in return for the financial investment in a consumption behaviour [5]. For example, when consumers choose a car, they buy it because they believe it's their "right choice". Before and after the purchasing decision, they perceive the value. When choosing a car, some people choose gas mileage as a key parameter, some other people choose brand as a key parameter.

In general, perceived value consists of functional value, emotional value and social value. For a car, the comfort of seat is a functional value for users, but the feeling of superiority when driving a nice car is a social value [6].

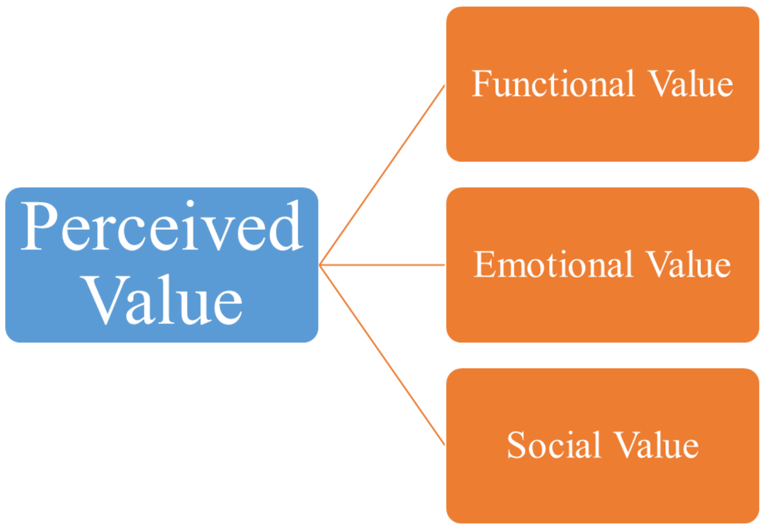

Fig. 4. Three types of perceived value

In that sense, if we could articulate what is the perceived value, then we could design the product to achieve the values. Functionality, one of the key pillars of TRIZ philosophy, is closely related with perceived value. As it point out, what we should focus on should be the practical use or benefits that an engineering system brings to the user, instead of the engineering system itself. By definition, functionality is the quality of being functional, i.e. achieving customer perceived value. In TRIZ, for a certain function, we have certain tools to improve it. For example, Function oriented search (FOS) provide a possibility to improve the functions [7]. So the authors suggest use a Perceived Value-Function-Parameter triangle to define the MPV.

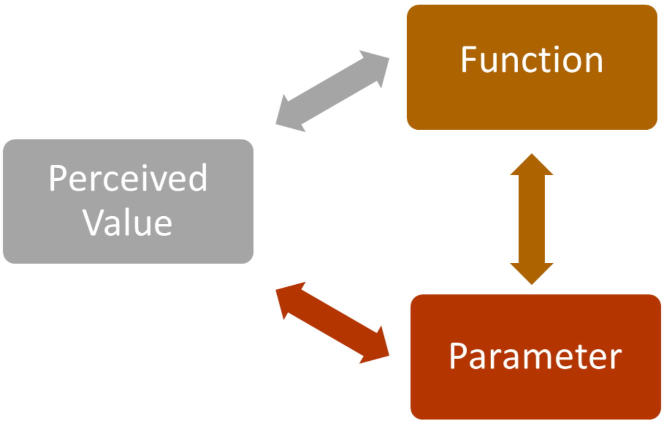

Fig. 5. Perceived Value-Function-Parameter Triangle

For example, when we use washing machine, the perceived value is fresh and clean clothes, and the function of washing machine is to clean clothes, the parameter is efficiency of cleaning. See below table for more examples.

Table 1

Example of Perceived Value-Function-Parameter

Product	Perceived Value	Function	Parameter
Shaver	Clean Chin	Cut hair	Length of hair and its variability after shaving
Chopstick	Convenience during dining	Move food	Effectiveness with different type of food
Bike	Easy transportation	Move People	Speed

However, there are still 2 questions regarding MPV. Firstly, is MPV a single MPV or a group of MPVs? As we may be already aware, for a simple product, we may make decision based on a single parameter, but for most products, there is no single parameter that could create perceived value and satisfaction. For a ball pen, maybe we only make decisions based on the writing performance, but for a car, few people make decisions based on only one parameter.

Secondly, are MPVs fixed for a certain product? Or are MPVs a clusters of parameters but different combinations really make the difference? The author suggest that due to the variability of preferences among different people, there are no fixed MPVs. However, we could define the key MPVs and create a MPV pool, and we could produce different product concept based on combinations of MPVs.

Overall, the author suggests to study the functions and parameters based on the following process:

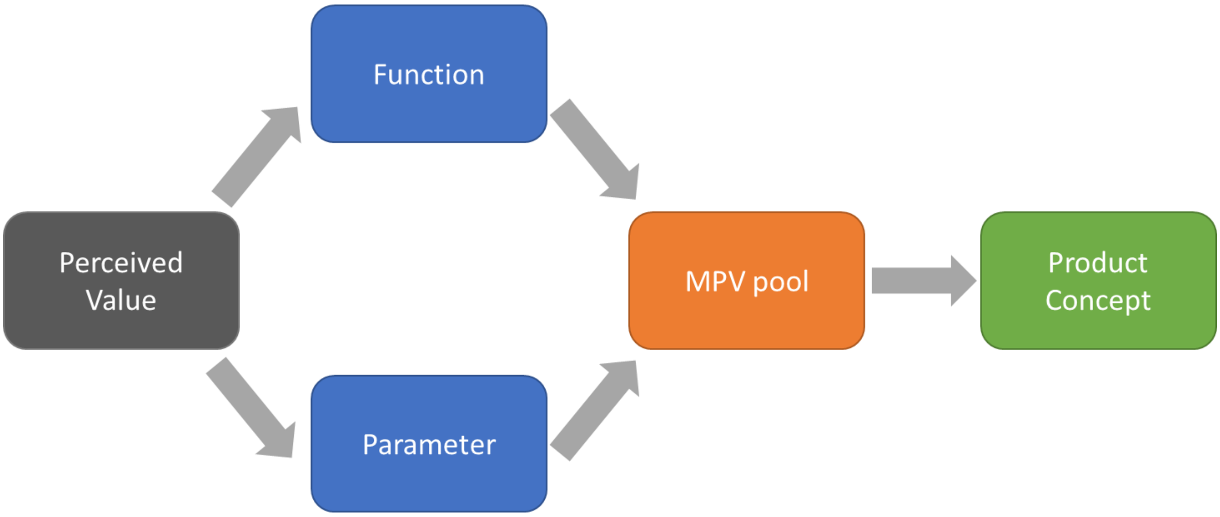

Fig. 5. Overall thinking process of MPV based product concept development

4. Perceived value and hidden customer need tools

Perceived value is the collection of benefits that customer/consumer gets in return for the financial investment in a consumption behaviour. According to Zeithaml [5], perceived value is “consumer’s overall assessment of the utility of a product (or service) based on perceptions of what is received and what is given”. Values are criteria consumers use to justify their actions such as purchase decisions. [8]

Consumer’s perceived value, one of the powerful marketing forces in the 1990s, is of increasing importance for both academics and practitioners in the twenty-first century [9]. A critical review of the perceived value literature revealed that the concept has been scrutinised from utilitarian perspectives including price or benefits/costs ratio and from broader psychological perspectives [10]

Sheth et al. [6] suggest that perceived value consists of five sub-dimensions: functional, social, emotional, epistemic and conditional value. Further progress suggests conditional value to be non-applicable at product level because it only reflects temporary and situational benefits [9]. And mainstream psychologists suggests that interest and curiosity is a certain type of emotion [11], so we mainly refer perceived value as functional value, emotional value and social value.

Functional value is defined as “the perceived utility acquired from an alternative’s capacity for functional, utilitarian or physical performance”. Social value is defined as “the perceived social utility acquired from an alternative’s association with one or more specific social groups”. Emotional value is defined as “the perceived utility acquired from an alternative’s capacity to arouse feelings or affective states”[6].

Regarding perceived value, there are already tools from other disciplines that have addressed. When we identified a certain group of target customers, there are 3 tools that the authors use most frequently for identifying perceived value.

Ethnography. Ethnography is the systematic study of people and cultures. It is designed to explore cultural phenomena where the researcher observes society from the point of view of the subject of the study [12]. Ethnography has its roots planted in the fields of anthropology and sociology, and its application in market research has been quite effective. [13] Ethnographic market research comprises a range of techniques, but a key characteristic of all is the need to talk to customers in their own environments, where they tend to be more open and honest in their answers, and to directly observe them using products rather than relying on explanations of how they use products[14]. From ethnography we could understand the perceived values and also some understanding about the parameters. Ethnography could help identify all 3 types of perceived values: functional, emotional and social values.

ZMET. The Zaltman metaphor-elicitation technique (ZMET) is a technique that elicits both conscious and unconscious thoughts by exploring people's non-literal or metaphoric expressions. It was developed by Dr. Gerald Zaltman at the Harvard Business School in the early 1990s. It can be used to elicit consumers' meaning about the personal relevance of a topic and then map those meanings as mental models [15]. The term mental model is a broad term that include attitudes, emotions and feelings, symbols, actions, goals, personal values, images, memories of past consumption events, and sensory experiences, etc. The output of ZMET include personal mental map and group consensus map, etc. ZMET could be used to find out the perceived values. ZMET is normally used for identifying emotional and social values.

Repertory Grid Technique. Repertory Grid Technique is essentially a method of eliciting constructs and analysing relationships between them. Elements (alternative events, states, or entities) and constructs (dimensions of similarity and difference between elements) are central to knowledge representation in repertory grids. The most basic form of repertory grid is a rectangular matrix with elements as columns and constructs as rows. Each row-column intersect in the grid contains a rating showing how a person applied a given construct to a particular element [16,17]. With a Repertory Grid study, we understand the major criteria of consumers' decision making. Repertory Grid Technique is more suitable for functional and emotional values.

Using the tools, we could have a pretty clear picture about the perceived values. Then we could start to think about the key functions and main parameters. For a typical consumer product development project, the author suggests to do 20-30 repertory grid interviews, 10-20 ethnography contextual interviews and 10-20 ZMET interviews.

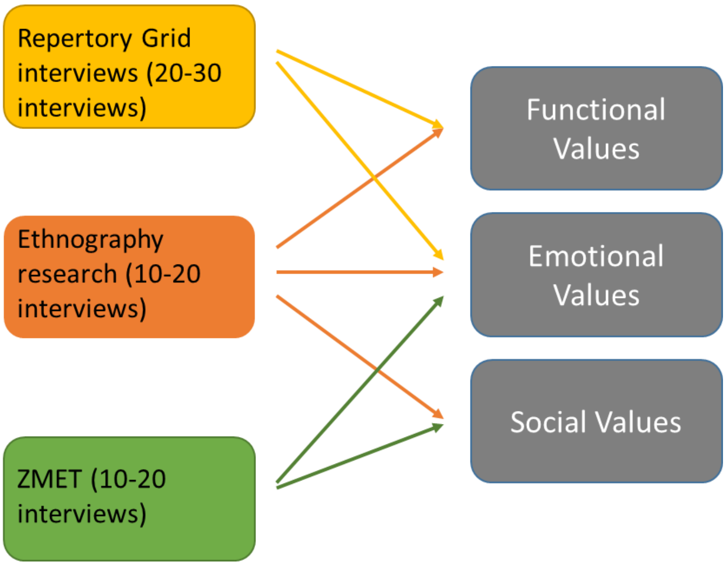

Fig. 6. Different tools with different results

For example, in a research study about vacuum cleaner, we used all the 3 research tools. In the Repertory Grid Analysis, we tried to analyse the criteria consumers use to differentiate different product include convenience of use, ability to clean in multiple situation, and noise. And in ethnography research, we found that consumers use specific measures to determine whether the house is clean or not. For example, if the floor is shining, if there is no dust the hidden corner, then it is clean. Also, they get frustrated because after using the vacuum cleaner, they still have to use mop or rag to clean the stains on the floor. In ZMET, we found that using vacuum cleaner to clean house mainly help to enhance the sense of "home", where you could enjoy safe and easy-going time, and pleasant relationship with family members. Also, housewives see themselves as the manager of family health and hygiene. They feel proud if the family is healthy and hygienic. Finally, the feeling of "under control" is quite important for housewives, if there is something they "must do" but "could not do", they get frustrated. For example, if there are a lot of dust and hair in the corner of bedroom, but they could not clean it as it's not accessible, they feel anxious. Combining these tools, we have a much deeper understanding about the perceived values of the consumers.

5. Parameter of Perceived Value (PPV)

When we have a profound understanding about customer perceived value, we have very good basis for future product development. Parameter of Perceived Value (PPV) is the parameter that defines the level of perceived value. When we understand the customer perceived value well, then we could study the parameters that determines the perceived value. As there are functional value, emotional value and social value, PPV is actually a group of parameters. We could build up a PPV pool according to the customer research. For example, in the vacuum cleaner project, if one of the perceived value from consumers is the ability to clean in multiple situation, then one of the PPVs should be effectiveness of cleaning different kinds of corners.

For every single perceived value, there is at least 1 PPV, and because PPV is the deterministic parameter, it is not the design specifications. When we have a complete list of major customer perceived value, then we have a complete list of PPVs, i.e. a PPV pool.

6. Key functions, criteria and parameters.

When we have a PPV pool, then the next question is how should we pick the key values and key parameters to focus on? By definition, MPV is the main parameter of value and should be the most important parameter.

When we combine S-Curve and Kano model, we could have a new perspective of MPV. As shown in below figure, we could divide the S-Curve into 3 different phases: excitement phase, performance phase, and basic phase. In stage I, MPV is still an excitement attribute, as it is not widespread yet; in stage II, MPV is a performance attribute, and in stage III & IV, MPV becomes a basic attribute. In that sense, the author suggests that we should see MPV as a dynamic concept instead of static concept. In some stage, it is a MPV, and sometime later, it may not be MPV anymore.

So in different stage, a parameter may or may not be a MPV. In excitement stage, as the parameter is not still the mainstream yet, so it’s still not a MPV. In performance stage, it is the MPV as it’s the most important contributor of customer perceived value. In basic stage, it is not MPV anymore, as customer satisfaction level does not increase along with the parameter.

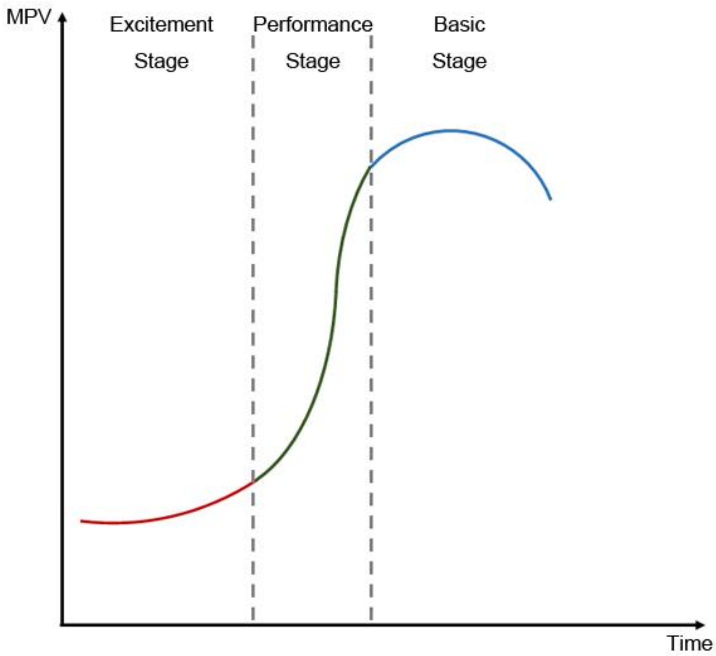

Fig. 7. Kano version S-Curve

Also, when we take different parameters into account, we could map them on the S-Curve. Along with time, the parameters move towards the right direction. In this model, MPV is defined as the PPVs in the performance stage. So instead of defining the only MPV, the author suggests to define a PPV pool, in the PPV pool, every parameter could be a MPV, depending on whether it’s in the performance phase. See below figure.

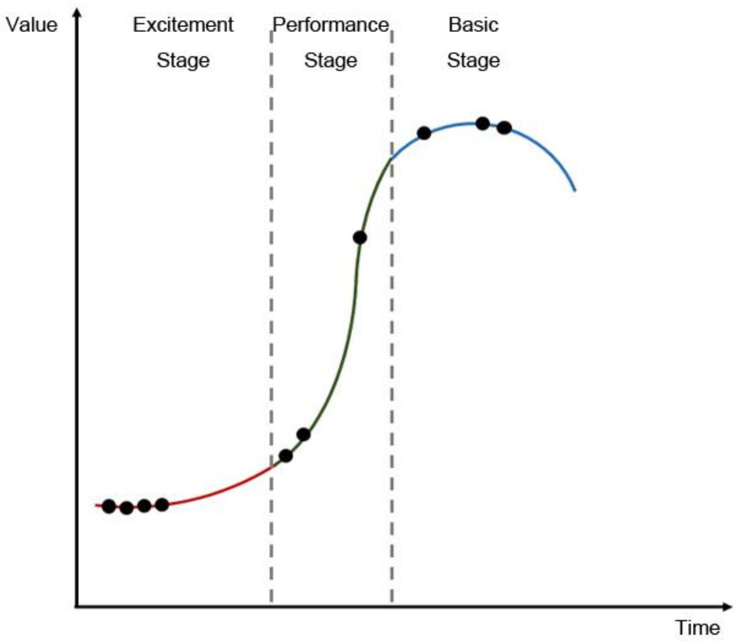

Fig. 8. PPV pool mapped on S-Curve

For example, currently, for electrical car, there are several PPVs, such as recharge mileage, charging speed, cost per mile, 0-100km/h acceleration time, auto-drive safety, remote control accuracy, audio recognition accuracy, etc. See below illustration.

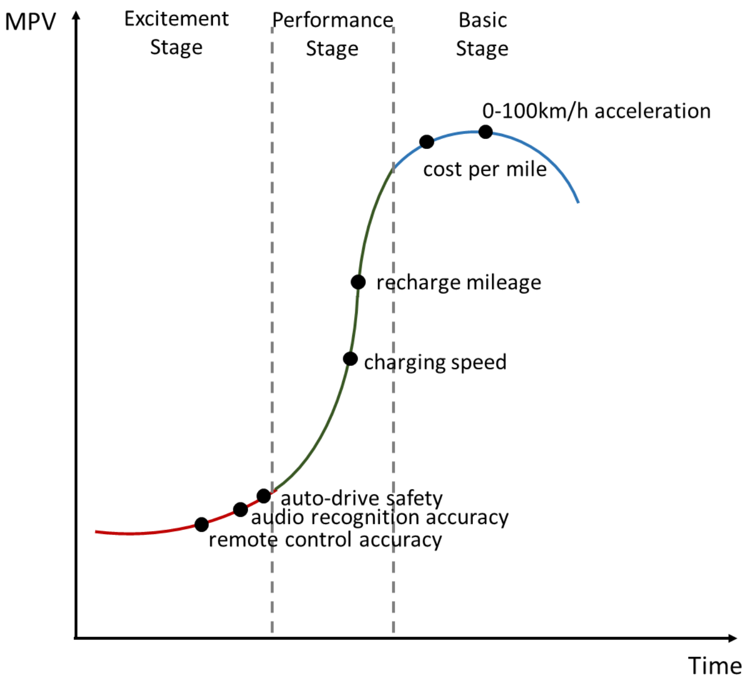

Fig. 9. PPV pool mapped on S-Curve: an example of electrical car

7. Ideation and product concept development

After mapping the PPVs, then we could combine different PPVs and come up with different product concepts. Normally, we should define a MPV (in performance stage), and then we could combine with other PPVs.

8. Algorithm for MPV-based product concept development

For better application, the author developed an algorithm to articulate the process.

Step 1 Customer profile. Choose a specific target customer group and describe them. For example, Pink Collar workers, female, 25-45 years old, fashionable and healthy lifestyle.

Step 2 Application scenario and perceived value. Study the target customer and identify perceived values using hidden customer need research tools, such as ethnography, repertory grid techniques and ZMET.

Step 3 Define key functions and PPV pool. Based on perceived values, define the key functions and MPVs.

Step 4 Map PPVs on the Kano version of S-Curve.

Step 5 Concept Development

9. Case Study.

Background: A team of product developers are developing a new shower and they are searching for new product concept. The product itself is already quite mature, and the company need a differentiated product to increase market share and profit margin.

Step 1 Customer profile. They choose the female white collar workers as their target customer. Their age range is 25-45, married with a kid, fashionable and healthy lifestyle.

Step 2 Perceived value. After studying Study the target customer and identify perceived values using hidden customer need research tools.

Table 2

The Shower Case Study: Consumer Perceived Values

Functional Value	1. Clean body 2. Sense of immersion 3. Convenience of usage 4. Clean for special purpose 5. Listen to music 6. Keep skin healthy and beautiful

Emotional Value	1. Reduce Stress 2. Feel young and energetic
Social Value	1. Connection with lover

Step 3 Define key functions and PPV pool. Based on perceived values, define the key functions and PPVs.

Table 3

The Shower Case Study: Perceived Values-Function-Parameter

	Perceived Value	Key Function	PPVs
Functional Value	1. Clean body 2. Sense of immersion 3. Clean for special purpose 4. Listen to music 5. Keep skin healthy and beautiful	1. Spray water 2. Immerse body 3. Clean private part or clean for kids 4. Play music 5. Maintain skin health	1. Spray volume per second 2. Water shape and angle 3. Constant temperature 4. Easy Control 5. Water purification 6. Audio quality 7. Skin care effectiveness
Emotional Value	1. Reduce Stress 2. Feel young and energetic	1. Relax skin 2. Refresh body	1. Water massage effectiveness 2. Refreshing effectiveness
Social Value	1. Connection with lover	1. Improve sense of intimacy after shower	1. Quality of interaction during and after shower

Step 4 Map PPVs on the Kano version of S-Curve.

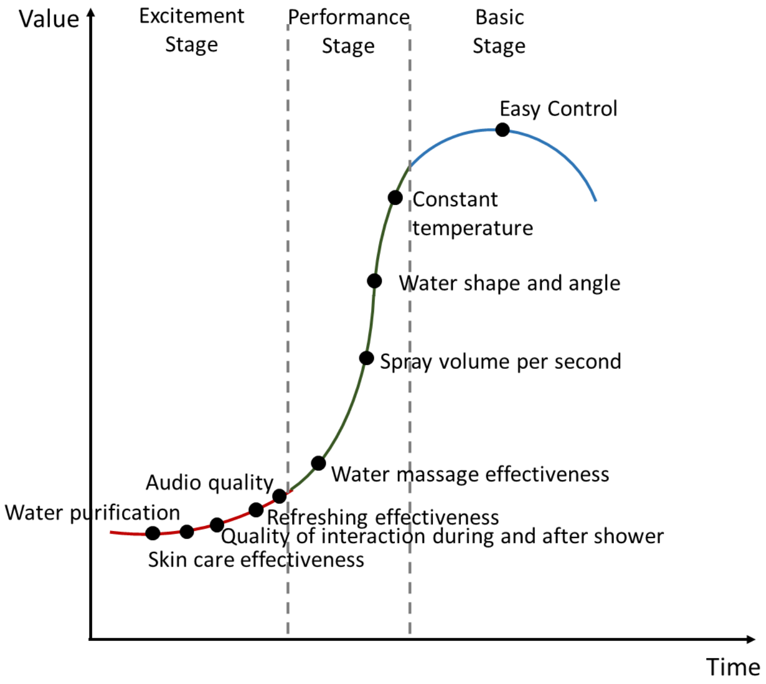

Fig. 10. The Shower Case Study: PPV pool mapped on S-Curve

Step 5 Concept Development

Combining the PPVs together, the team developed several product concept. See below a partial list.

Table 4

The Shower Case Study: Product Concept Development

Key Function	Combination of PPVs	Product Concept
Spray water	Spray volume per second; audio quality	Music fountain shower
Spray water	Water shape and angle; refreshing effectiveness	Multiple refreshing spray patterns
Massage body	Water massage effectiveness; quality of interaction during and after shower	Couple water massage shower
Clean and recover skin	Water purification; skin care effectiveness	Waterbank skin refreshment shower

10. Conclusion & Further issues.

In conclusion, this article explores the principles and practices about how to use hidden customer need tools to identify and evaluate MPVs (Main Parameters of Value), how to generate product concept using MPVs. When using TRIZ in concept development, the PPV pool would be essential. The author suggests that MPV is dynamic and changing, thus we should manage the PPV pool and track the dynamics of MPVs. The author also proposed a

Perceived Value-Function-Parameter logic to identify the key MPVs. We need to use market research tools to identify perceived values, including functional, emotional and social values, then we could analyze and define the key functions and parameters based on perceived values. This initial research implies new opportunities in discovering new product concepts, which extend the applicability of TRIZ. The future research should explore a more detailed version of MPV algorithm, and how does MPV link to other TRIZ tools is also a field of interest.

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CONJUGATE EVOLUTION - TWO NEW EVOLUTIONARY SUB-TRENDS

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Abstract

Trend increasing ideality of system, not only means to increase the ideality of man-made systems (MMS), but also means to increase the ideality of the human system (HS). Therefore, it is necessary to make unified thinking that we added the HS into MMS. MMS and HS are forming a evolution trend -- conjugate evolution.

Two new evolutionary sub-trends have been identified by the author: one is the trend of increasing the biological characteristics of MMS; another is the trend of syncretism of MMS and HS, both belong to the Trend increasing ideality of system. These two sub-trends have different starting points: first one is to make the MMS to learn from biological systems, including learn from HS, i.e., people make better and better MMS; second one is to make the MMS to strengthen HS, i.e., MMS serve people better and better. Finally, two new trends converge in human bodies -- the most advanced creatures in nature.

Keywords: technology systems (TS), man-made system (MMS), human system (HS), evolution, trends, biological properties, syncretism, conjugate evolution

1. TS, MMS and HS:

The systems in substance world are divided into natural systems, MMS and composite systems. In most cases, the technical systems (TS) are composite systems composed by the man-made system (MMS) and natural systems (humans, plants, air, etc.). Here MMS has the similar meaning with Artificial or Synthetic systems (Fig 1).

When previously talked about "Trend of increasing ideality of system", we tend to think about that talking TS refers only to MMS, which is actually one of the inertia thinking. The author believe that the "Trend of increasing ideality of system", not only to be used for MMS, but also for the HS, i.e., to increase the ideality of HS. Therefore, it is necessary to make unified thinking that MMS and HS.

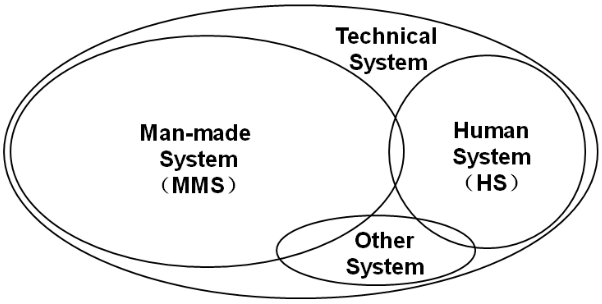

Fig 1. The scope of Technical System

All MMS are made to meet people's needs, and the design purposes to build the MMS (such as dentures, hearing aids, clothing, transportation, etc.), are to compensate human capacities, and to expand human functions (such as space telescopes, mass memory, the Internet, the human brain chips, etc.), therefore increase the ideality of TS, finally increase the ideality of HS. MMS and HS are conjugate evolution, promote each other, it is a clear trend.

Increasing the ideality of HS, require us to do the R&D around people. In order to meet the people-oriented social requirement, the times is calling for the new evolutionary trends. Authors propose two new evolutionary sub-trends as bellow.

2. Sub-trend of increasing the biological characteristics of MMS

In the development process of a TS, increasing certain biological characteristics is a clear trend: from the outside to the inside of the structure, from elements to subsystems, from execution systems to the control systems, from electromechanical bodies to organisms, etc. Evolutionary path is:

Appearance with biological characteristics → Partial structures with biological characteristics → Overall structure with biological properties → Man-made non- biological body + Partial biological body → Man-made non-biological body + complete biological body.

(1) Examples of appearance with the biological characteristics:

such as toys with various animals shape, a stadium with a bird's nest appearance, a submarine and high-speed rail appearance like a dolphin, aerofoil like a bird wing section, man-made turf, etc.

Germany's Universum Science Center Bremen's shape is both like a whale, and a giant mussel (Fig 2).

Fig 2. Universum Science Center Bremen

The Seed Cathedral in Shanghai looks like a hedgehog. It is formed by 60,000 slender transparent fiber optic rods. Each fiber optic rod is 7.5 meters long and encloses one or more seeds at its tip. All the rods pass through the wall or the dome. Light can transmit along with the optic fiber rod from different direction (Fig 3).

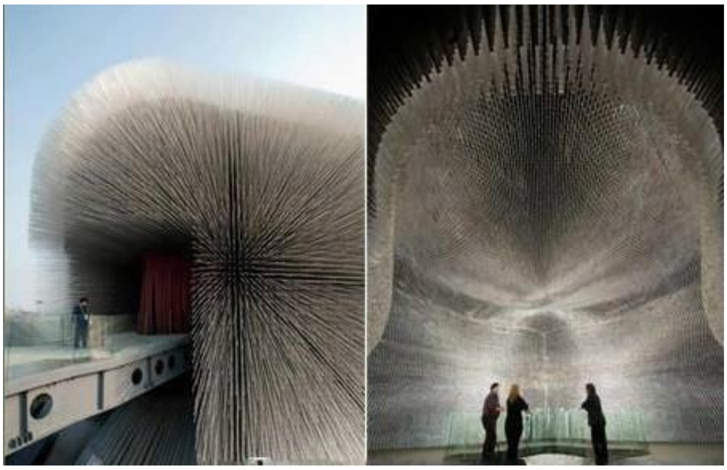

Fig 3. Seed cathedral at Shanghai

(2) Examples of partial structures with the biological characteristics:

Hankook and Pforzheim University in Germany jointly designed three cool future racing tires, wherein:

Boostrac desert type design, its unique honeycomb structure can spread out into a large gear tire, greatly enhance the grip capability; Alpike snow type can laterally transform to increase ground area like a bear's paw, it is suitable for the paved road with thicker snow; HyBlade rain type has fin-type blades and drainage channels, it is suitable for fast and stabilized driving on the road with water (Fig 3).

Fig 4. Boostrac desert type, Alpike snow type, HyBlade rain type

(3) Examples of overall structure with biological properties:

Examples:

Robots with visual, auditory, tactile and talking capacities; man-made insects; swimwear imitated shark skin structure.

Observing a shark skin with electron microscope, it is composed by the numerous "Cortical Scales Protruding". These scales' protruding have grooves in the longitudinal direction, so water flow on its surface can be adjusted, and can prevent from forming whirlpools or vortex turbulences. This special skin structure, will not only prevent parasitic algae in their body, but also significantly reduce water friction. Swimmers wearing this swimsuit, have broken the world records many times (Fig 5).

Fig 5. "Cortical Scales Protruding" and swimsuit with this structure

(4) Examples of Man-made non-biological body + Partial biological body

Examples: absorbable suture catgut; a biochip containing human genes; biological machines (Fig 5).

Fig 6. A biochip containing human genes and the biological machines

(5) Examples of Man-made non-biological body + complete biological body

Examples: blinking keyboard used by Hawking; detector dogs wearing test equipment; spacecraft with animal experiments, etc. (Fig 7).

Fig 7. Blink keyboard that is being used by Hawking

August 2015, several Germany insect experts suggested to train bees as a new detect tool of narcotics. First, trainer placed bees into odor to be identified, put syrup in front of them, let the bees to build up the link "smell" and "food", later, if encounter the same odor they would stick out their tongues.

After the training, the bees will be put into a special suitcase (with a group of 6 bees) , there are some infrared inductors inside. Once 3 inductors detected bees’ tongue, it will alarm. (Fig 8).

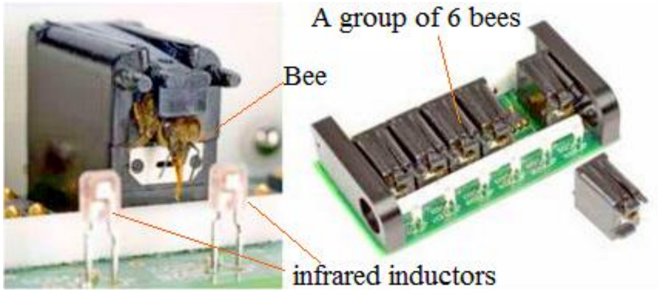

Fig 8. Infrared inductor detected bees tongue, to alarm the narcotics.

Although this sub-trend looks very like the bionics, but the examples (4)-(5) are not belong to bionics. It is not the MMS learn some features from creature, but directly added the creature (HS or animal) into MMS, creature become a sub-system.

3. Sub-trend of syncretism of MMS and HS

MMS are all built to meet the needs of people, and therefore a clear trend is MMS gradually entering into HS: body surface attachments, mutually embedded with human bodies, or implanted into human bodies so that it becomes part of HS, thereby significantly increasing human capabilities.

This trend has two intertwined evolutionary paths:

MMS substitute human element (vitro → body surface → cross embedded → vivo) → MMS substitute human function (vitro → body surface → cross embedded → vivo) → MMS substitute human organ (vitro → body surface → cross embedded → vivo)

(1) MMS substitute human element (vitro → body surface → cross embedded → vivo) ---- dentures perhaps were the first man-made element partially embedded in the human body. Artificial bone, synthetic skins, etc., also belong to such products.

Earlier 2016, scientists at Stanford and UC Berkeley both developed entirely synthetic skins that are sensitive enough to detect the touch of a butterfly. Both rely on a combination of flexible rubber with either nanowires or electrodes. And synthetic "skin" would do cyborg double-duty: ultra-sensitive human prosthetics or robot limbs (Fig 9).

Fig 9. Synthetic skins are sensitive enough (body surface)

Percutaneous pedicle screw spinal surgery is a minimally invasive surgery. The steel nails replaced the defective part of lumbar to support and position the lumbar (Fig 10).

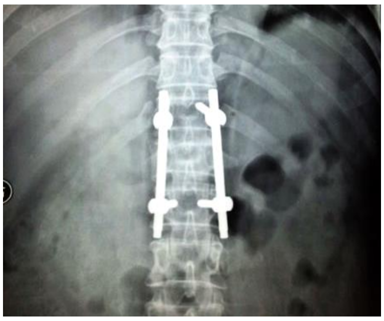

Fig 10. Steel nails to support and position the lumbar (vivo)

(2) MMS substitute human function (vitro → body surface → cross embedded → vivo) ---- Wearable devices are developed rapidly in recent years, from rings, watches, bracelets, arm bands, to intelligent glasses, intelligent helmets, smart underwear, power exoskeleton. These devices can exchange data, perceive information, in self-organized networks, etc., mainly to substitute, strengthen and extend the functions of HS.

Samsung Innovation Lab has developed a prototype of sensor to detect whether the wearer stroke (judgment function). Its appearance is similar to a headset, and connected with a mobile phone to monitor brain waves of the wearer and match with the particular software algorithms, it can determine the wearer's risk of stroke and whether he will need any medical treatment (Fig 11).

Fig 11. Wearable device monitoring whether the wearer stroke (body surface)

Powered exoskeleton is an intelligent bionic wearable device to extend the human movement functions. Exoskeleton worn on the human body, perceive human moveable intention, to drive servo mechanism in the exoskeleton to produces the corresponding action (Fig 12).

Fig 12. Powered exoskeleton (Cross Embedded)

Deeply embedded human eye camera can imitate human visual function. It consists of three parts: a tiny camera (use existing colonoscopy camera), a battery, and a wireless transmitter that can capture pictures and then sending them into a computer. The wearer can use an external radio control devices to control shooting (Fig 13).

Fig 13. Camera embedded eye orbit (Embedded)

(3) MMS substitute human organs (vitro → body surface → cross embedded → vivo) ---- Man-made system entering human body, is an important trend in medical technology development. Many parts of HS, like skin, eye, blood vessel, brain, stomach, etc., can be the sites of implantation. There are some temporary implant devices, such as imaging capsule, can perform inspection tasks in human's stomach and intestines. There are also some permanent implant devices, such as a man-made vein. According to the USC's report, professor Theodore Berger has developed the world's first brain prosthesis, an implantable hippocampus that may help patients regain the ability to store new memories. Copy and substitute the human memory will be realized in the near future.

A bone-anchored hearing aid (BAHA) is a type of hearing aid based on bone conduction. It is primarily suited for people who have conductive hearing losses, unilateral hearing loss, single-sided deafness and people with mixed hearing losses who cannot otherwise wear "in the ear" or "behind the ear" hearing aids (Fig 14).

Fig 14. Bone-anchored hearing aid (BAHA) (body surface)

Implanting a chip into human's brain has a successful precedent. The newspaper of Hong Kong "Wen Wei Po" has reported that, Harbison, a British color blindness artist, was given a surgery to implant a special chip into his brain, then he can "listen" the unique vibration frequency to distinguish each color, so that his monochrome world has been granted full colors (Fig 15).

Fig 15. Implanting a chip into human brain to "listen color" (Vivo)

Today, all TS are gradually turning smart even intelligent, we have to seriously think about the relationship between HS and MMS. According to this sub-trend, at ultimate intelligent stage, a large number of micro-intelligent MMS could be implanted into certain HS to substitute some of their subsystem (tissue or organ, even some nerve docking), to significantly enhance the abilities of people, reduce or eliminate the risk of disease.

4. Conclusion

Often, TS are composite systems that contains both MMS and HS, or even other natural systems. Increasing the degree of Ideality of TS, will not only increase the Ideality of MMS, but also ultimately increase the Ideality of HS.

Two new evolutionary sub-trends have been identified by the author: one is the trend of increasing the biological characteristics of MMS; another is the trend of syncretism of MMS and HS, both belong to the Trend increasing ideality of system. These two sub-trends have different starting points: first one is to make the MMS to learn from biological systems, including to learn from HS, i.e., people make better and better MMS; second one is to make the MMS to strengthen HS, i.e., MMS serve people better and better. Finally, two new sub-trends converge in human bodies -- the most advanced creatures in nature, to form the Conjugate Evolution.

The updated architecture of TS evolutionary trends (Fig 16).

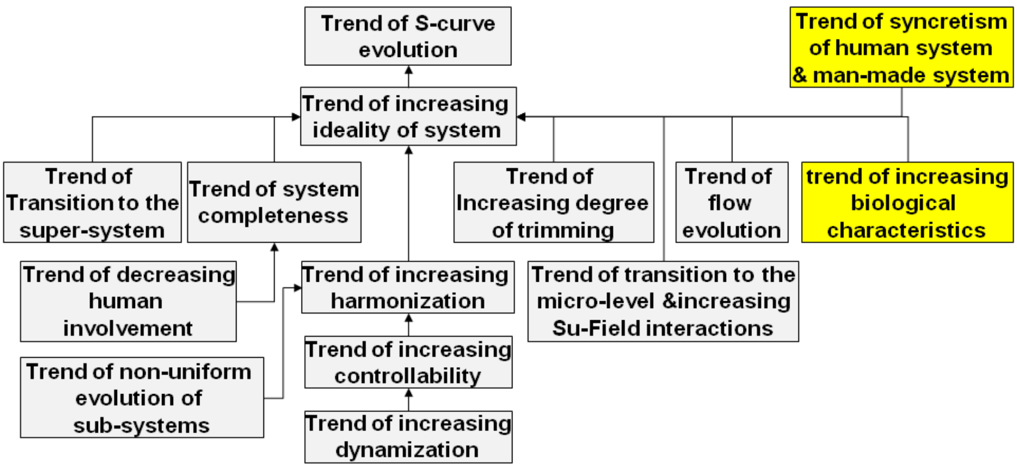

Fig 16. The updated architecture of TS evolutionary trends

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COUPLED FUNCTIONS FORMULATION

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Abstract

Being a component of function analysis, rules for function formulation are well formalized and usually don't cause problems for researchers. A function is defined as an action of one system component (function carrier) upon another one (function object) that leads to variation of function object parameters. As a rule, the primary focus in the course of analysis is placed on change of state (parameters) of function object. Function performance in actual systems is always accompanied by change of function carrier state. For example, if function carrier heats function object, this function object cools the function carrier at the same time. Actually, we deal with a pair of oppositely directed functions. However, distinct recommendations regarding formulation of such pair functions are missing.

The article is based on practical experience of the authors. It deals with formulation of such pair functions and contains recommendations on:

- Classification of coupled functions
- Formulation of coupled functions
- Proper choosing between model with one function and model with coupled functions.

Keywords: TRIZ, Function analysis.

1. Introduction

According to the definition, a function is an action of one object (engineering system component) upon another one [1, 2]. However, one of the fundamental principles of natural science lies in the fact that action is always an interaction.

This principle in classical mechanics was formulated as early as in XVIII century in the form of 3rd Newton's law and later it was accepted as a basis for quantum mechanics in the form of Heisenberg uncertainty principle. In thermodynamics this principle is manifested in the second law of thermodynamics, In electrodynamics – in the form of Maxwell's equations, in electrical engineering – in the form of Lenz's principle, in chemistry – in the form of Le Chatelier principle, and so forth.

Though in natural science this principle was not generalized, such generalization took place in philosophy in the form of law of unity and struggle of opposites. So when university students listen to their philosophy lecturers, they don't suspect that they learn about one of most fundamental principles of their future profession (whatever field of engineering it would belong to).

2. Coupled functions in engineering systems

Accordingly, in engineering this principle is manifested actually everywhere. Brake shoes decelerate vehicle wheel, and at the same time the wheel abrades brake shoes in the course of braking process. At all steps of mechanical processing, the process of cutting by a tool is accompanied by a process of tool destruction (blunting). Electrical current (i.e. current of charged particles) heats a conductor, and at the same time this current is dissipated (slowed down) by the conductor. Moreover, dissipation of charge carriers in the last example represents a direct cause of heat release.

In the general case, performance of any function is accompanied by performance of another oppositely directed function describing the influence of function object on function carrier (i.e. product upon tool). From this point on in this article we will call these two functions “coupled functions”, and term “counter function” will be used to describe relationship of these two functions to one another.

With strict approach to the analysis, it follows from the aforesaid that when one builds a function model, he should supplement any function with an oppositely directed counter function. Obviously, such step would make function model more sophisticated (though formulation of counter function usually does not cause any difficulties). At the same time, benefits of such approach are not obvious at all. Let’s make an attempt to classify coupled functions and then formulate recommendations on their introduction into function models on the basis of our classification (or on disregard for these functions).

It is important to be noted: coupled functions are not a pair of independent interactions between two system components but two interactions when one of them is caused by another and scales of these interactions are depend each to other.

3. Classification of coupled functions

In practical work on model construction one function (out of the pair) is defined quite unambiguously – one should start building a function model from the main function of a system and then the model is supplemented with other functions. Let’s call this function in a pair as the first function (perhaps, it would be better to call it the “main” or “primary” function, but these terms are already used in function model).
Based on our experience in function analysis, we distinguish the following typical situations, in which it is feasible to analyze coupled functions:

3.1 First function is a useful one, while counter function is a harmful one

Such a situation is encountered quite often when analyzing the operation of engineering systems, in which either tool wear or significant variation of tool parameters takes place. Two typical situations could be singled out depending on the rate of such variation (i.e. on level of harmful function performance):

- Time scale of analysis involves significant variation of tool parameters; and
- Time scale of analysis is much less than characteristic time of significant variation of tool parameters.

For instance, when driving in a nail with a hammer, the latter (tool) moves the nail in (thus transferring kinetic energy to the nail). In its turn, the nail absorbs kinetic energy when being moved in, and with each hammer stroke this energy is completely expended and hammer speed drops to zero. From the standpoint of process duration, this function (i.e. energy absorption) is a harmful one.

Now an opposite situation – slow wear out of tool. When a nail is driven in by a hammer, the latter moves the nail in, while the nail wears out (abrades) the operating surface of the hammer. In actual practice this wear out is often neglected and the counter function is excluded from the model. This is quite an adequate approach, but only with one reservation. It is important to keep in mind that slow wear out would lead in the final end to significant variation of parameters of the first function carrier and worsening of parameters describing the level of this function performance (when a hammer is used on a permanent basis, its operating surface would get deformed, thus requiring adjustment). In other words, when a counter function is excluded from the model, there is a risk to omit important factors influencing the level of first function performance.

3.2 First function is a useful one, and counter function is also a useful function

Similarly, two typical situations could be singled out depending on the rate of parameters variation:

- Time scale of analysis involves significant variation of tool parameters; and
- Time scale of analysis is much less than characteristic time of significant variation of tool parameters.

Let's give two simple examples. Heating element of an electric teakettle heats water. A counter useful function is performed concurrently – water cools down the heating element. This function is very important for normal operation of the teakettle because switching the kettle on without water inside it would quickly lead to breakdown of heating element. This is a typical situation of implementation of coupled functions operating in one time scale.

A cone in electrodynamic loudspeaker is held in place by means of a special-purpose suspension (usually it is made of polymeric material or rubber). The suspension performs useful functions – "to hold in place", "to direct". Concurrently, the cone in the course of its operation "kneads" suspension, i.e. changes its mechanical properties. As a rule, an acoustic system acquires optimal sounding only after several hours of operation. This is a counter function having significantly larger time scale as compared to the first function.

A similar classification can be used in the case when the first function of the pair is a harmful one.

3.3 First function is a harmful one, and counter function is a harmful one

Destruction of mirrors by light flux may take place in high-power laser systems. This process is described by a pair of harmful functions: "mirror [partially] absorbs light flux" and "light flux destructs mirror". It is interesting that the first function is performed all the time, while the counter function emerges only starting from a certain threshold value of light flux power.

3.4 First function is a harmful one, while counter function is a useful one

Such a situation may arise, for instance, in the course of analysis of heat flows in electronic devices. A situation "element A releases heat and heats element B" is usually described by harmful function "A heats B". Counter function "B cools A down" can be omitted from consideration despite its importance.

4. Recommendations on formulation and use of pair functions

Despite the fact that functions always exist in pairs, not always counter functions should be included in the model and analyzed in detail. Nevertheless, a number of typical situations could be distinguished, in which analysis of coupled functions is feasible:

4.1 In the case of two coupled useful functions - for example, multi-layer packaging materials on the basis of aluminum foil. The function “to stop oxygen flow” is performed by an oxide layer on aluminum foil surface. Concurrently, oxygen performs the function “to produce oxide layer”. In the majority of such cases, the first function and counter function are in cause-effect relationship and often separated in time: barrier properties of foil (function “to stop (oxygen”)) emerge due to the fact that that counter function of oxygen is already performed (“to oxidize (metal surface)”). A more general phenomenon – self-lining widely used in transportation of bulk materials: a flow of substance forms an additional barrier layer, and this layer, in its turn, slows down the flow (thus, protecting the housing proper).

4.2 In the case of coupled function of “useful function + harmful function” type. Actually, we deal hear with a contradiction – “a useful action should be performed for the purpose of its usefulness, and at the same time it shouldn’t be performed due to the presence of harmful function that accompanies the said useful action”. A contradiction of this type is easily identified in a doubled conflicting pair (when function carrier implements useful function directed on element B and harmful function directed on element C). For coupled functions such a contradiction is much less obvious. Disadvantages of this type are identified later in the course of cause-effect analysis (in the mode of search for “payment factors”). But application of coupled functions notion allows identifying relevant disadvantage at early stages of analysis in the form of contradiction. Let’s take a system for biological treatment of sewage water as an example (removal of organic matter from sewage water). Bacteria decompose organic matter to phosphates, but phosphates suppress bacterial activity (that same old Le Chatelier principle, but with an emphasis on biology). Currently the problem is solved partially by artificial intensification of bacterial activity, which leads to a large number of secondary problems. Formulation of problem in the form of contradiction (with subsequent resolving of the latter) would enable to increase system efficiency quite significantly.

4.3 And, finally, failure-anticipation analysis [3, 4]. Though failure-anticipation analysis often gives good results, its methodology is characterized by the presence of very important but poorly algorithmized step – namely, identification of latent harmful functions. The efficiency of performance of this step depends largely on practical skills of researcher. At the same time, formulation of harmful functions and inclusion of ALL of THEM in the model would help to compile a list of latent harmful functions. Later these functions can be analyzed according to well-described methodology of failure-anticipation analysis. Particular emphasis should be placed on counter functions having “long-term time scale”, i.e. to those functions that slowly change parameters of function carrier (i.e. just to those functions that are usually omitted as being of low significance). For instance, vacuum-evaporating apparatuses are widely used in production of potassium fertilizers. The customer of one specific project indicated to the authors five problems associated with sudden breakdown of apparatuses. All resources of repair and maintenance department were allocated for the elimination of these problems. However, simple analysis of repair and maintenance department expenses showed that 80% of time and funds are spent to eliminate subsequences of usual sluggish corrosion.

5. Concluding remarks

Based on the experience of the authors, after construction of function model, researcher should analyze all functions included in it for the significance of coupled functions. Though it may seem that such step is characterized by high labor consumption, actual expenditures of time and labor are not too significant. A standard operationally-capable model usually includes 6-9 components and 10-15 functions. Formulation of counter functions (as indicated above) usually is not difficult (at this stage a researcher is well acquainted with the subject matter of a project). Checking the functions identified in this way in terms of high significance or low significance may turn out to be more difficult that identification of these functions. But it can be exceptionally useful from the standpoint of function analysis efficiency.

Particular emphasis should be placed on situations when a pair of oppositely-directed functions implements positive or negative feedback. That same old Le Chatelier principle implements typical negative feedback – up to complete stop of chemical, electrochemical, biological and other processes. In contrast, coupled functions associated with corrosion processes are characterized by typical positive feedback. The larger is a degree of corrosion, the higher is the corrosion rate. Irreversible consequences often appear all of a sudden. Another example – situation with traffic on the roads. Minor increase in traffic density (as compared to previous point in time), which is insignificant when taken alone, suddenly lead to traffic jams (or obstruction on conveyor belts in production processes).

The presence of important coupled functions represents an indirect indication on feasibility of conducting the function analysis in a more detailed way – by one system level. In other words, it makes sense for researchers to consider function carrier as an independent engineering system and conduct functional modeling for this function carrier.

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DEEP UNDERSTANDING AND APPLYING FLOW ANALYSIS, SIMPLIFIED DETECTIVE FLOW CLASSIFICATION MODELS

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Abstract:

According to several years' experience of applying flow analysis in industries, combining with the Su-Field Analysis, authors simplified 10 defective flows into 4 defective flow models, and then built up a new process to use flow analysis techniques to solve engineering problems.

A case study shows that this new process can be used to "The low pass rate of production of powder metallurgy (a new material) pressure die forming", the problem collapse of products' edge and vertex are resolved based on flow analysis. As a result, the pass rate was increased by 16%, while the ideality is improved based on the minor change of the pressure dies.

Keywords: Technical System (TS), Flow Analysis (FA), Su-Field, defective, model, trend, evolution, minimal problem, cause, collapse, edge, vertex, powder metallurgy, forming, dies.

1. The Brief Introduction of Trend of Increasing Flow Efficiency

Historically, G. Altschuller was the first to formulate the "Trend of Minimum Energetic Conductivity". Altschuller's student, Igor Gridnev had put forward an idea to propagate this trend to the entire period of the system's life. At the same time he has found out that in the course of TS evolution the conductivity of its components carrying energy flows normally increases.

This trend had a lot of names: it was called the "Trend of Increase in Conductivity", "Trend of Increasing Conductivity of Substance, Energy and Information Flows", "Trend of Increasing Conductivity of Flows", "Trend of Optimization of Flows". Finally, it was named "Trend of Increasing Efficiency of Flows", or, "Trend of Increasing Flows Efficiency".

Flow analysis (FA), trend of increasing flow efficiency, are the new tools in modern TRIZ system. Following please see "Architecture of evolution trends" (Fig.1).

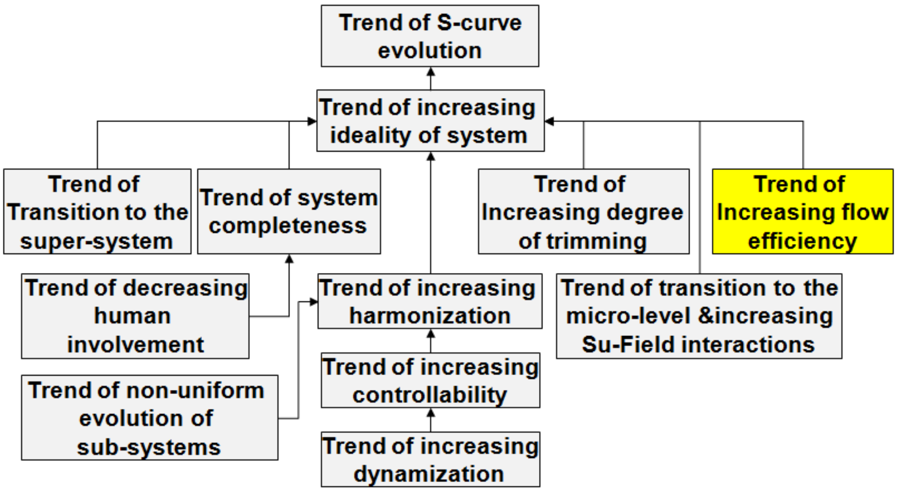

Fig.1 Architecture of evolution trends

This new and innovative analysis method can increase the TRIZ application scope to solve engineering problems. In recent years, authors have tried to use FA as a primary tool, combined with other TRIZ tools, to solve some engineering problems in different industries.

While using FA to solve the problem, firstly, we must convert the engineering problems into the corresponding problems of defective flows. There are two type (A, B) of defective flows (Conductivity and Usability), and 10 typical problems of defective flows.

(A) Conductivity defects: 1. bottleneck; 2. stagnant zone; 3. poorly transferable flow; 4. long flow; 5. channel has higher resistance; 6. low flow density; 7. large number of flow transformations

(B) Utilization defects: 1. gray zone; 2. channel damages flow; 3. flow damages channel; 4. flow damages itself. (Fig.2).

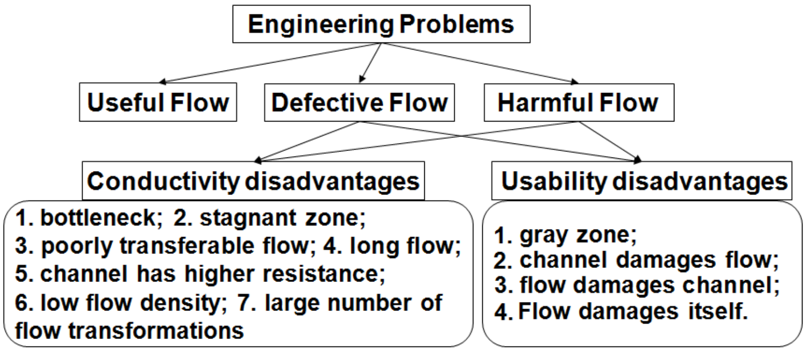

Fig.2 The 2 kinds of defective flows

Then we can use the problem solving tools offered in the “Trend of increasing flow efficiency”, to eliminate problems of defective flows that have been found.

2. Build-Up Simplified Defective Flow Classification Models

When solving problems with FA, the authors believe that converting engineering problems into the corresponding 10 defective flows is a difficult and complicated process. Then authors worked to analyze the defective flows combined with Su-Field analysis model. After a rigorous and careful researching, the authors successfully converted 10 defective flows into 4 defective flow models. With the simplified defective flow classification models, can help people to analyze the flows combined with Su-Field analysis tools, and achieve the mastery. (Fig.3)

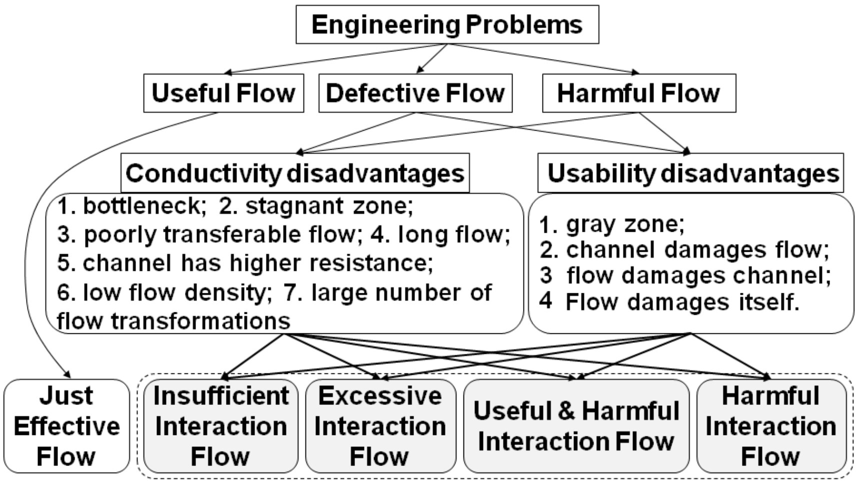

Fig.3 Build up the simplified defective flow classification models

This figure is one of the basic processes that authors use regularly to analyze an engineering problem, combined with SFA (Su-Field Analysis). (Fig.4)

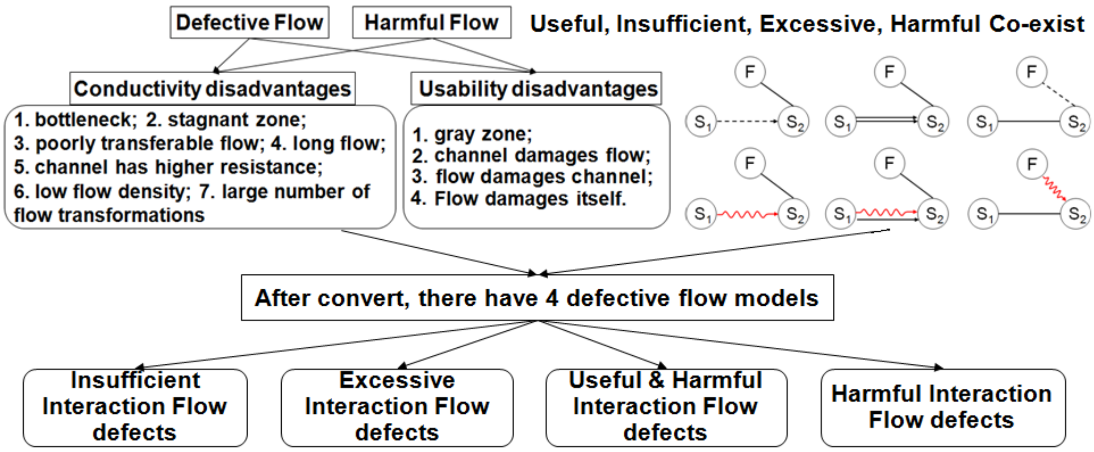

Fig.4 A basic processes to analyze an EP

3. Establish A New Process To Solve Engineering Problems

Now we can establish a new 5 steps process to solve the problems: (Fig.5)

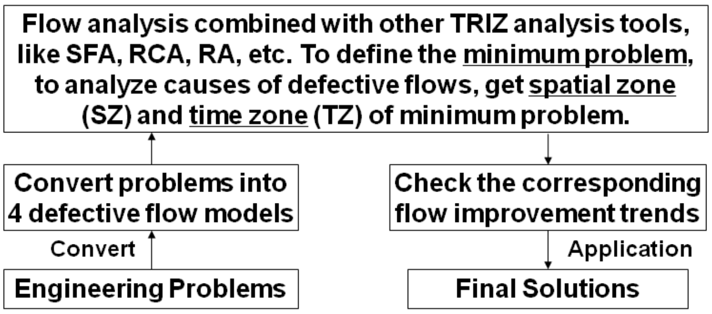

Fig.5 The main process of solving the problems with FA

Step 1: state the Engineering Problems (EP) -- Describe the process defects of production in details, i.e., the spatial and time zone of the problem happened.

Step 2: convert EP into 4 detective flow models -- Make FA, convert the problems in production process into the new defective flow model.

Step 3: make FA with evolution trends and with other TRIZ problems' analysis tools, like SFA, RA (Resource, Analysis), RCA (Root Cause Analysis) , etc., the analysis purposes are to define the minimal problem, analyze causes of defective flows, and finally, get spatial zone (SZ) and time zone (TZ) of the minimal problem;

Analyze the defective flows in the minimal problem zone, by applying SFA, RCA and RA, at the different system levels. (Fig.6)

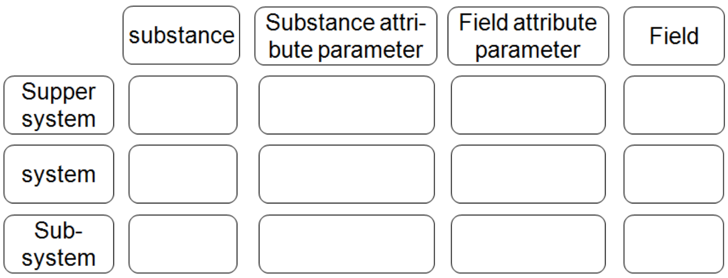

Fig.6 System level SFA, RCA and RA

Step 4: check all possible corresponding flow enhancement trends -- Indentify some available flow evolution trends that could solve the problems, aiming at the cause of defective flows formed.

The principles of above step, is "first easy to post difficult". Applying identified flow trends one by one, gradually solve the engineering problem, find out the feasible trends.

Step 5: get final solutions – Transfer the feasible trends to real solutions.

Below is the detail process of solving the problems with FA (Fig.7):

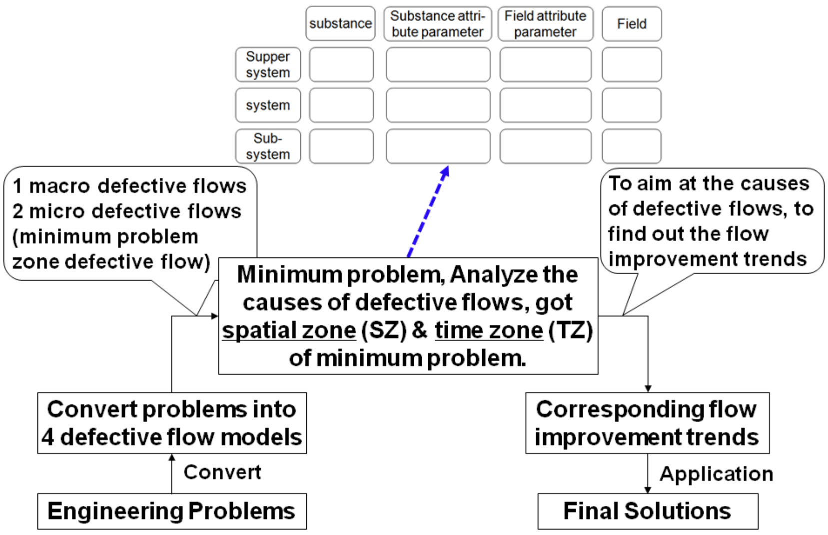

Fig.7 The detail process of solving the problems with FA

4. Case Study: Solve A Real Engineering Problem (EP)

Authors have successfully resolved several EPs in the fields of "electronic circuits, Internet hardware, cloud platforms, powder metallurgy", these EPs all belong to "hard EPs in industries and enterprises". The solving ideas are very simple, directed at the root target of the problems. For example: a case study "Solving the problem of low yield production of power supply circuit with a 2mm red gum line ", has been published in a new book "TRIZ Enhancement and Practical Applications", by Professor Min Zhao.

The following content describes how the authors use this new 5 steps process to solve a real hard EP in the pressure die forming industry.

Step 1: State EP (situation description): The low pass rate of pressure die forming of powder metallurgy production with a new material.

When customer used a new type of metal powder material in the production of pressure die forming, if product has a complex shape, after the upper die and lower die separation, the slight collapse will be happen at the product’s edges or vertex, cause the product waste. The product pass rate is only about 75% in this case. (Fig.8)

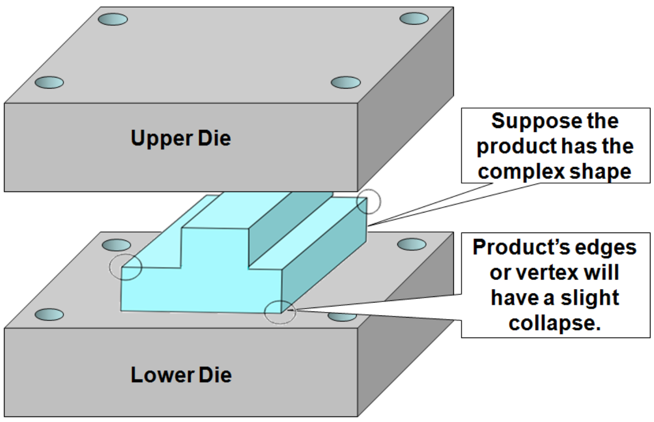

Fig.8 Complex product's shape will cause collapses of edges & vertex

Step 2: Convert the problems "The low pass rate of pressure die forming of powder metallurgy production with a new material" into the 4 defective flow models.

Step 3: Make FA, authors found the minimum zone of the defective flow, identified the minimum problem zone of defective flow model, also, found that the useful flow and harmful flow were coexistence.

(C) A harmful interaction flow made a separating trend.
(D) A useful flow was an insufficient flow with the converging trend.

If the harmful flow (C) is greater than the useful flow (D), the edge or vertex will collapse during upper and lower dies' separation; If the useful flow is greater than the harmful flow, the product will keep a good shape.

The minimal problem <u>spatial zone</u> (SZ) is the local tip position where harmful flow is greater than the useful flow.

The minimal problem <u>time zone</u> (TZ) is the moment of upper and lower dies' separation. (Fig.9).

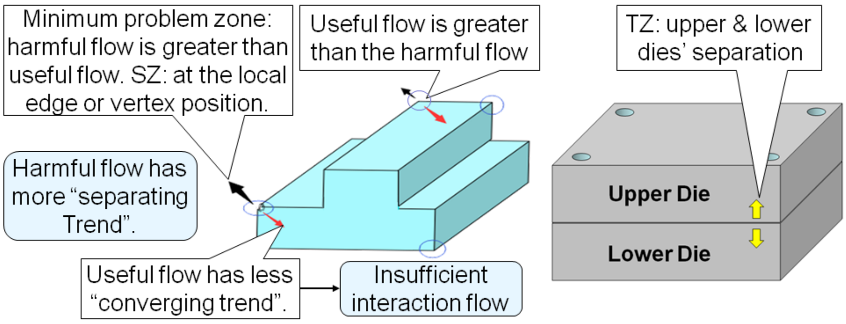

Fig.9 The minimum problem of SZ & TZ

Then, authors analyzed the defective flows in the minimal problem zone, by applying SFA, RCA and RA, at the different system levels. (See Fig.10)

	Substance	Substance Parameter	Field Parameter	Field
Super system	Press machine, Power Supply	Pressure, Electromagnetic field	Pressure, Temperature, Electromagnetic field	Electric field, Magnetic field, Gravity field
System	Upper and lower dies, Powder, Magnetic core	Shape, Adhesion force, Density, Time	Magnetic field intensity、Magnetic field, Pressure, Temperature	Magnetic field, Pressure field, Thermal field
Sub-system	Dies material, Powder shape	Material molecular shape, Force	Substance energy field	Electron field, Molecular field

Fig.10 System level SFA, RCA and RA of the EP

Base on the causes of "more separating trend (harmful flow)" and "less converging trend (insufficient interaction flow)", making a comprehensive "System level and Su-Field resource analysis", from 3 levels (system, super system, sub-system), and at the 4 sections (substance, field, substance parameters, field parameters), try to find the spatial/time causes in the minimal defective flow zone.

At this step, the authors strongly emphasized the cooperation between TRIZ experts and industry experts to find out the real causes.

Make a RCA (Root Causes Analysis) about why "separating trend" is more than the "converging trend".

Through RA (Resource Analysis), we can try to find the forming reason of harmful flow and other defective flows.

RCA for cause of "more separating trend (harmful flow)"：Die inner corner shape, Adhesion force, Electromagnetic force, etc.

RCA for cause of "less converging trend (insufficient interaction flow)"：Powder material, Die material, Die pressure, Pressing time, Temperature, etc.

Step 4: Aiming at the root causes for the defective flows, finding some available flow improvement trends that may solve the problems. (Fig.11) We selected 2 options (E, F).

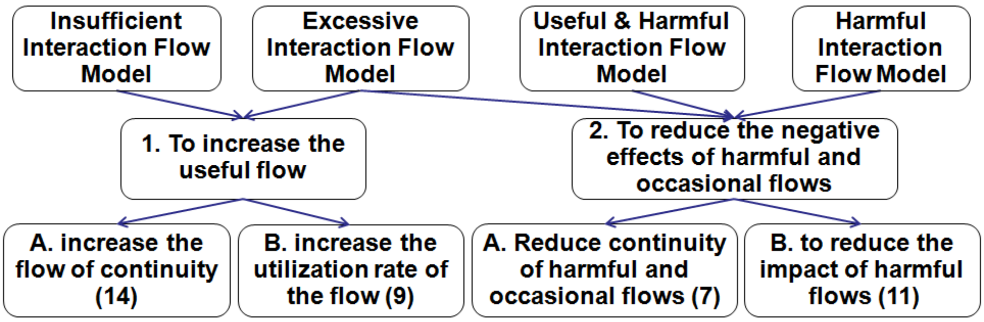

Fig.11 Find some available flow improvement evolution trends

(E). Solving the problems come from “harmful interaction flow model”, check the "reduce the impact of harmful flows (11 items)", find out the corresponding flow improvement trends. (Tab.1)

To reduce the impact of harmful flows (11 items)	
1 Incorporate Gray Zones in the Path	
2 Reduce flow density	
3 Eliminate Resonance	
4 Reassign flows	
5 Incorporate a Flow and an Anti-flow	√
6 Change flow	√
7 Change damaged objects	
8 Pre-set substance, energy, information to neutralize flow	√
9 Bypassing	
10 Transport flow to supper system	
11 Recycling or reply accidental flow	

Tab.1 Find out the corresponding flow improvement trends (11 items)

Base on the above analysis results, select three (5, 6, 8 items) flow improvement trends to reduce the harmful slow.

"5 Form a flow and anti-flow; 6 Change flow; 8 Pre-set substance flow, energy, information to neutralized flow."

To apply above available flow improvement trends one by one, with a principle of the "first easy to post difficult", we can gradually solve the EP.

(F). Solving the problems come from "insufficient interaction flow", check the "Increase the continuity of flow" (14 items), find out the corresponding flow improvement trends (Tab.2)

To increase the continuity of flow (14 items)	
1 Reduce the conversions of flow	
2 Transition to a more efficient flow effect	√
3 Reduce the length of flow	
4 Eliminate gray area	
5 Eliminate bottlenecks	
6 Use bypassing	
7 Expand the flow channel of each independent part of the conduction	
8 Increase the density of flow	√
9 Apply an useful effects of a flow to another flow	
10 Apply an useful effects of flow to channel of another flow	
11 Let a flow carries other flow	
12 Assign many flows a channel	
13 Change flow to increase the continuity of flow	
14 Let flow pass through the channel of supper system	

Tab.2 Find out the corresponding flow trends (14 items)

Base on the root causes of insufficient action in accordance with the flow: Select two (2, 8 items) flow improvement trends to eliminate the insufficient flow:

"2 Transition to a more efficient the flow effect; 8 Increase the density flow."

Step 5: Applying selected items to make the feasible solution. (Fig.12)

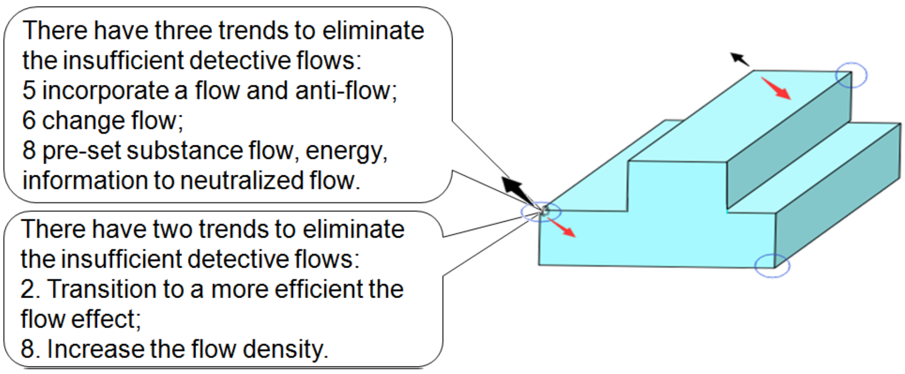

Fig.12 Select the corresponding trends as the solutions

According to the principle of "first easy to post difficult", these 5 flow improvement trends were applied to adjust the production process of powder metallurgy die. Select 1 or 2 of them to make a feasible solution. Finally, authors achieved very good results: the most collapse of products' edge & vertex were eliminated, the pass rate increased to 90%.

5. Conclusion

Deep understanding and applying FA is very useful to solve the EPs. Authors used the FA to build up a new process to analyze and solve EPS.

Firstly, a minimal problem zone have been defined by using FA, the defective flows have converted into defective flow models. Secondly, the substance, field and parameters of the system, subsystems and supper system have been analyzed with the resources of substances and fields. Lastly, the major causes what resulted the defective flows have been found, and some flow improvement trends have applied to solve the problems.

A case study shows that this new process has been solved an EP "The low pass rate of pressure die forming of powder metallurgy production with a new material". The problems of collapse of products’ edge and vertex have been well resolved. The products pass rate has increased to 90%, while the ideality has been enhanced based on the minimal change of the pressure dies.

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DEFINITION OF SYSTEM INNOVATION DEGREE AND ITS APPLICATIONS

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Abstract

Genrich S. Altshuller has proposed five levels of innovations (LoI). While, in creative works, people usually use this concept in a single direction.

To distinguish the difference of the innovations which belong to the same innovation level, this paper propose a new concept-System Innovation Degree (SID).

SID is a measurement to the innovations which locate at the same level of innovation defined by Genrich S. Altshuller.

With a practical case study, the main applications of SID in invention works are illuminated.

Keywords: Levels of innovations, Technical Predict, Patent Strategy

1. Introduction

Genrich S. Altshuller has proposed five levels of innovations (LoI) as Table 1 shows [1]:

Table 1. Levels of innovations

levels of innovations	Description	Knowledge Required	Object Status
Level 1	Technology Transfer -a simple improvement of a technical system	Within the trade relevant to that system.	Does not change.
Level 2	Knowledge Exchange -an invention that includes the resolution of a technical contradiction	From different areas within the industry relevant to the system.	Changed but not substantially.
Level 3	Knowledge Collaboration - an invention containing a resolution of a physical contradiction	From other industries.	Changed essentially.

Level 4	Knowledge Innovation - a new technology is applied which contains a resolution of contradictions with better approach to Ideal Final Result	From different fields of science.	Totally changed
Level 5	Innovation Networks - discovery of a new phenomenon or substances	New knowledge	Entire technical system is changed in which this object is used.

As we know, the high or low levels of innovations do not means the related solutions is good or bad, because a customer often reluctantly accepts substantial changes to his existing system. For solving a problem, he perceives that it is necessary to change something in the existing system, but he tries to implement these changes minimally to facilitate prompt introduction [1].

With the help of knowledge of levels of innovation, people can 1) predict the trend of existing technologies and products and 2) set up the patent strategy for his existing technologies and products.

While, according to the definition of the levels of innovations proposed by Genrich S. Altshuller, people can just distinguish the levels of innovation in a single direction. In other words, if there are two or more innovations which are labelled in the same level, how can people distinguish them?

Even though some people thought that distinguishing of the different levels of innovation is more important than the distinguishing within the same level [2], but in most enterprises, for the innovation usually is an asymptotical process with limitation of resources or some economic factors, people usually will choose the solutions within the same level of innovation, which indicates that distinguishing the degrees within the same level is meaningful.

2. Description of System Innovation Degree

In order to evaluate the degree of an innovation which is located at the same innovation level, a new concept is introduced which is called as System Innovation Degree (SID). It is to measure the innovations which locate at the same level of innovation defined by Genrich S. Altshuller. SID is distinguished by the knowledge applied for the solution. See Table. 2. for details.

Table 2. Description of System Innovation Degree

System Innovation Degree	1	2	3	4
Knowledge the Solution Applied	Within the trade relevant to that system.	From different areas within the industry relevant to the system.	From other industries.	From different fields of science.

With the help of SID concept, the degree of innovations can now be evaluated in the same level by a different direction comparing with LoI.

Same as the levels of innovations, even the SID is large or small does not means that the related solutions is good or bad, but with the help of SID, people can 1) predict the trend of existing technologies and products and 2) set up the patent strategy in a different direction comparing with the Levels of Innovations (LoI).

Using the LoI and SID, a whole picture for the technical predicting can be obtained in two-dimensions as showing in Fig.1.

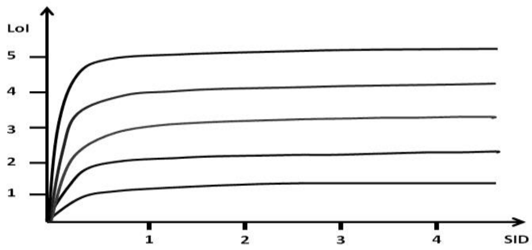


Fig. 1 LoI and SID

3. Case Study

Here, a practical case study has been introduced to show how the SID applies in the real invention job.

Fig.2. Wind Turbines in Working

http://img4.imgtn.bdimg.com/it/

Project name: Wind Turbine Improvement.

Project Description: Wind turbine works as the opposite of a fan using electricity to make wind, a turbine uses wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. The electricity is sent through transmission and distribution lines to a substation then sent to homes, businesses and schools.

Project Goal: Improves the productivity of the three blades wind turbine without increasing the cost. [3]

To simplify the process, solutions with the technical contradiction (TC) overcoming are chosen, it is clear that the solutions are belonged to level 2 defined by Genrich S. Altshuller.

To increase the rotate speed or torque of the generator in low speed of wind, people need to increase the surface area of the wind blade, but it will lead to increase of the length of the blade, thus will got a technical contradiction (TC 1), which is shown in Fig.3.Of course, there are a series of pairs of TC in this project, and the solving process is analogical. It is unnecessary to go into details.

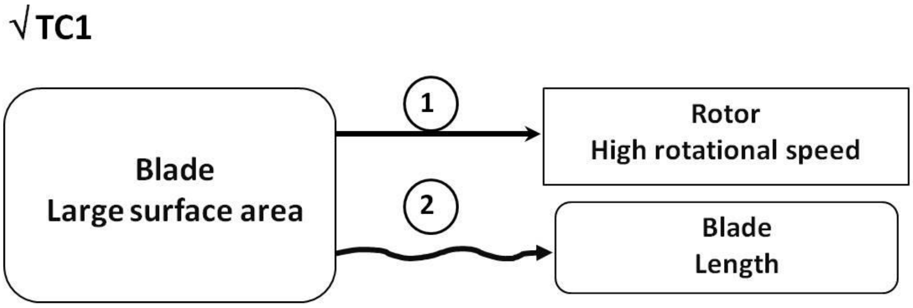
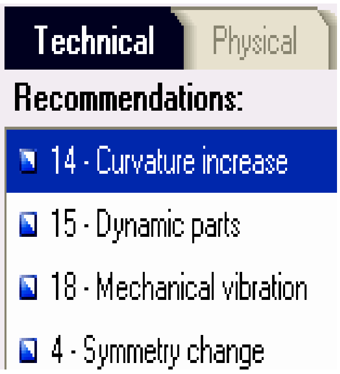


Fig.3. TC 1 in Wind Turbine [3]

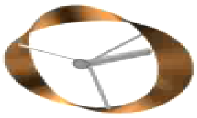
By means of Altshuller's Matrix, four recommendations for TC 1 overcoming are gotten, shows in Fig.4.

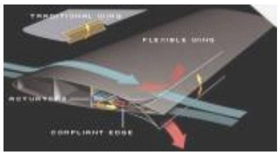


Improving	Area of moving object
Worsening	Length of moving object

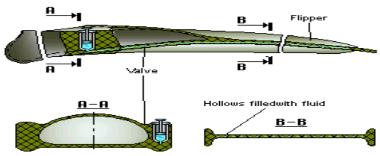
Fig.4. Recommendations for TC1 overcoming [3]

Based on these recommendations, following solutions are obtained, as shown in Fig.5. [3]





(1) (2)



(3) (4)

Fig. 5. Final Solutions for TC 1 in Wind Turbine Project [3]

(1) Blade in form of MOBIUS Belt; illuming from 14 **Curvature increase**
(2) Flexible Wing – Blade; illuming from **18 Mechanical vibration**
(3) Variable-rigidity flipper – blade; illuming from 15 **Dynamic Parts**
(4) Doubled propeller – Doubled blades; illuming from **4 Symmetry Change**

For solution (2)—Flexible Wing, the knowledge within wind turbine is required. For solution (3)—Variable-rigidity flipper, the knowledge from the solar power generation is required, which is a different areas within the industry relevant to the wind turbine. For solution (4)—Doubled propeller, the knowledge coming from aerospace industry is required, Finally, for solution (1)—Blade in form of MOBIUS Belt, the mathematics knowledge is required, which is a different field of science.

According the criteria of SID mentioned above, each solution's degree of SID has been ranked respectively as shown in Table.3.

Table 3. System Innovation Degree for TC 1 Solutions in Wind Turbine Project

System Innovation Degree	1	2	3	4
Knowledge Applied	Within the trade relevant to that system	From different areas within the industry relevant to the system	From other industries	From different fields of science
Solutions	Flexible Wing – Blade	Variable-rigidity flipper	Doubled propeller – Doubled blades	Blade in form of MOBIUS Belt
Solution No.	(2)	(3)	(4)	(1)

Once ranked the SID of the solutions which belong to the same lavel of innovations, people could make use of these different solutions in differnt way. They may use the soluions (2) and (3) in the current product's renovating or improving and make use of the solutions (1) and (4) in setting up the patent stratagy. The reason is the solution (2) and (3) are not substantial changes to the existing system but solution (4) and solution (1), in particular,are substantial changes to the existing system.

4. Conclusion

Traditional or Classic TRIZ proposed five levels of innovations, but it is not enough to distinguish the difference of the innovations which belong to the same levels. The distinguishing of those innovations is helpful for setting up an integrated patent strategy and to predict the next step for an existing product or technology.

Acknowledgements

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DESIGN OF HANGING CHAIR BASED ON TRIZ

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Abstract

Because the lay problem of the folding chair in the narrow space needs to be solved, the TRIZ theory is introduced to solve it. The scheme of hanging guitar chair is established according to the goldfish and the multi-screen method, and the folding idea is obtained based on the dwarf method. In the designing process, some conflicts are occurred, and these conflicts are described by the standard engineering parameters, through querying the contradiction matrix, the recommended inventive principles are given, and five inventive principles are selected according the actual situation, and the solving schemes of guitar hanging chair are obtained. The hanging function of Ornaments chair is solved based on scientific effects, and the sizes, strength analysis results are provided.

Keywords: innovative design, guitar hanging chair, TRIZ innovative thinking tool, contradiction matrix, scientific effects.

1. Introduction

Fig. 1 the fixed chair [1]

Fig. 2 the folded chair [2]

Chairs are the necessary furniture in our daily life, most of the chairs are shown in Figure 1, which are a fixed form, and they occupy a certain space. And for the crowded space, such as school student dormitory, factory employee dormitory, they hope that a chair occupy a certain space in use, and when not in use, can reduce the space occupied, so the folding chairs are developed, which are shown in Figure 2. Although the folding chair to ease the demand for living space, it is still facing how to be stored, and a new type chair is necessary to be creatively conceived for the crowded room.

The innovative design about chair has not stopped, for example, Pan, et al developed a new kind of special-shaped shelf-chair which can be deformed and combined easily and can be used as a shelf based on TRIZ theory [3]. Yang, et al creatively accomplished a multi-functional office chair which can realize the normal, comfortable office, and the rest by using TRIZ theory [4]. Ma et al designed a computer chair by considering ergonomics which improves the various needs of the human to the computer chair, increases the comfort, reduces the incidence of occupational disease, and achieves satisfactory working condition [4]. Xu, et al created an office chair which are fit for modern office work according to the sitting behaviour [5]. Zhang, et al established a design method of working seat which can obtain the spatial position and basic shape of six seat parts accoding the healthy seated posture information, constructed the 3D model, and verified the theoretical design results [6]. Jia, et al also built an innovation method to design chair based on TRIZ theory which can creatively conceive the structure of massage chair [7]. Kulkarni, et al designed a transformable chair which would satisfy various needs of people by using TRIZ [8]. From these studies, TRIZ theory is a useful tool for designing the chairs, which can help us to generate various new concepts, and solve some difficult (such as conflicts) during designing process.

However, these studies more consider the comfortable and multi-function, do little concern for the storage problems after it folding. In this paper, TRIZ theory is as solving tool to innovative design the new chair, which it is not only reduce the space occupied during its period of no working, but also can use as an ornament.

2. The concept conceiving based on TRIZ innovative thinking tool

TRIZ theory help us overcome thinking inertia. In this design, the storage problem after the chair folding need be solved, so the concept of new chair for this problem need be created. The thinking tools, which is goldfish, multi-screen, small dwarf, are used to help us find the new concept.

2.1 Conceiving of the scheme of hanging chair based on goldfish and multi-screen method

TRIZ innovative thinking tools have a lot of tools to help people to think divergently, such as multi-screen method, STC (Size, Time, and Cost) operator method, goldfish, small dwarf method, the ultimate ideal solution, and so on [9-12]. Because the folding chair does not want to occupy the ground space is the fantasy, it is used to solve the goldfish method analysis.

According to the analysis process of goldfish, the chair innovation scheme conceiving is established, and shown in Figure 3. First the obstacles to achieve the fantasy is found, and then the conditions of realizing fantasy and the resources that can be used to realize those conditions are analyzed. Finally the idea with using the non ground space (such as walls, ceilings, here mainly refers to hang on the wall) is determined. It is not simple hanging on the wall, also would beautify the walls, so it becomes a decoration, and then the concept of ornaments chair is put forward.

Further used with multi-screen method (as shown in Figure 4) to analyze the problem what kind of decorative elements combined the chair, and the thinking is diverged. Considered music being enjoy for inspiration and spirit of young people, so the music element is selected to be combined with the chair, while guitar is more common musical instrument, and is loved by lots of young people. In a word, the guitar element is selected to combine with chair, and the scheme of hanging guitar chair is established, is shown in Fig. 5.

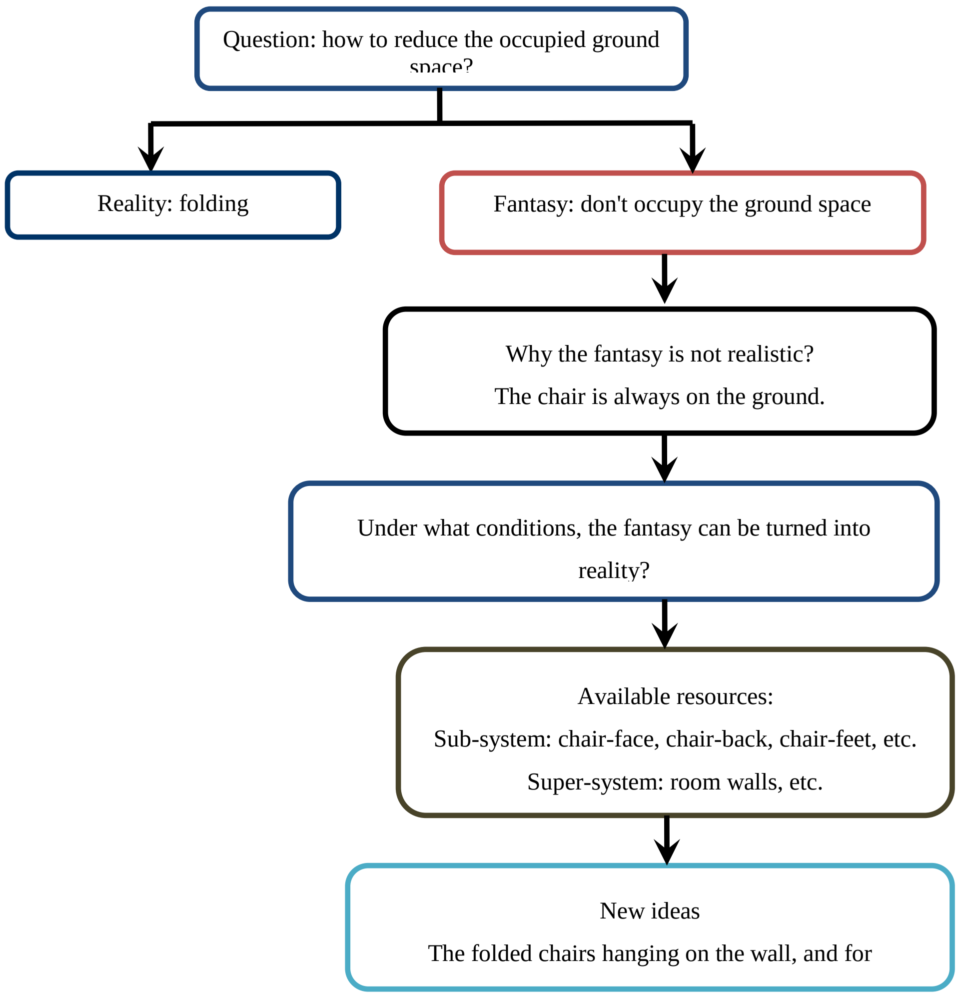


Fig. 3 The solving process of goldfish

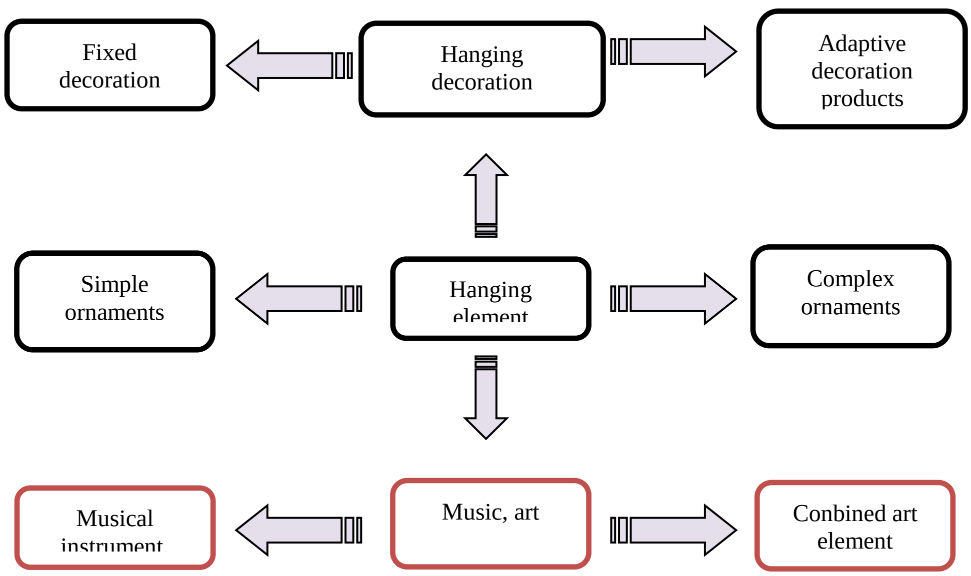
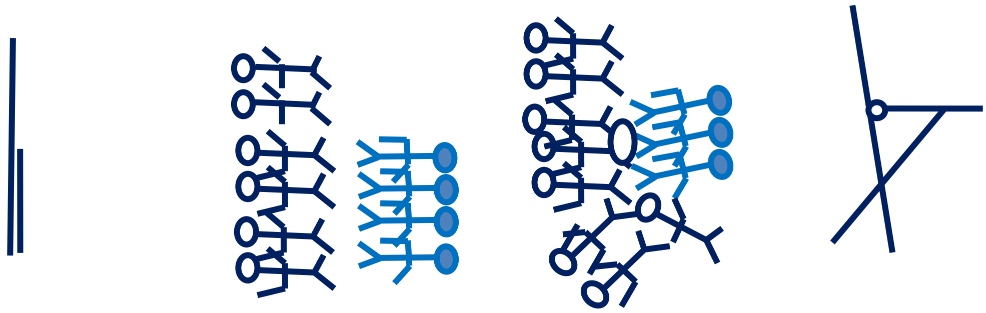


Fig. 4 Multi-screen

Fig. 5 The solution scheme: guitar hanging

2.2 Solving the folding problem based on the dwarf method

After the idea about chair that acted as guitar hanging decoration after no using is determined, the chair shoud be designed to foldable structure, wchich can perform the functions with sit and decoration. The dwarfs method in TRIZ theory is introduced to establish the chair's folding scheme. According to the analysis process of dwarfs method, first set up the dwarfs model of the original system, which the guitars is composed of the head, the neck and the resonance cavity, with two groups of dwarfs (head and neck for a group). And then the subjective initiative of the dwarfs is brought into play, the part dwarfs in the resonant cavity is divided to two layer, and these two layers can rotate mutually, and dwarfs in the neck and resonance cavity consis of two leg, which are supported the chair face layer, and they are across each other, so the preliminary folding scheme is established, and shown in Figure 6.



a) hanging plate structure b) the dwarf model of the original structure
c) improved dwarf model d) improved chair structure

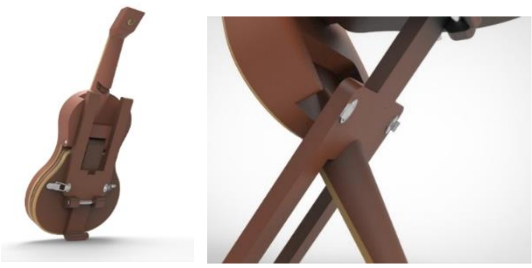


Fig. 5 The solution results: folding guitar hanging

3. Conflict solving in the hanging decoration chair designing based on the contradiction matrix

3.1 Conflict analysis

Some contradictions would be encountered in the design process of guitar hanging chair, such as, the contradiction between the reliability of the chair and the size of the folded part, ornaments coordination function (produced gloomy effect) and the support leg width (chair stress is influenced). For these conflicts, firstly, they are described by the standard parameters, querying with the standard engineering parameter in TRIZ theory, guitar hanging chair faced two contradictions: 27- reliability /3 - moving object size; 31- the harmful factors produced by object /10 - force (stress).

Table 1 Conflict parameter standardization

No.	Conflict	Conflict standard description
1	the contradiction between the reliability of the chair and the size of the folded part	27- reliability /3 - moving object size
2	ornaments coordination function (produced gloomy effect) and the support leg width (chair stress is influenced)	31- the harmful factors produced by object/ 10- stress

3.2 Querying from contradiction matrix

Based on the standard engineering parameter in TRIZ theory, the classical TRIZ contradiction matrix is queried, and shown in Table 2, the recommended inventive principles are obtained: 15 (Dynamics), 14 (Spheroidality-curvature), 9 (Preliminary anti-action), 4 (Asymmetry) (these four principle corresponds to the first contradiction); 35 (Parameter changes), 40 (Composite), 1 (Segmentation), 28 (Mechanics Substitution) (these four principle corresponding to the second contradictory). Comprehensively analyzing for the inventive principles, the inventive principles about 15, 4, 14, 1, 28 are selected to solve these two contradictions.

Table 2 Simple table of conflict matrix

	1～2	3	4～9	10	11 ～ 39
1～26					
27		15，9， 14 ， 4			
28～30					
31				35， 28， 1 ， 40	
32～39					

3.3 Analyzing for the principle solution

According to the selected inventive principles: 15 (Dynamics), 14 (Spheroidality-curvature), 4 (Asymmetry), 1 (Segmentation), 28 (Mechanics Substitution), some insight are gained: 1) leg is made to sliding structure, when a folding chair is spreaded to chair for people sitting, it does not affect the structural stability, and after it folded, the sliding leg can slip to the behind of guitar body surface, the appearance is not being affected. 2) the guitar style elements are intergated into the hanging chair, and the appearance of hanging chair is designed to be similar to the guitar surface, the decorative effect is enhanced. 3) the asymmetry structure of guitar is retained, which the shape of guitar is reflected in the new chair. 4) the resonant cavity part (the dwarf method also got the similar conclusions), is divided into two layers, the two layer can be rotated each other. At same time, it is split out a support leg, this leg can be relatively slided in the behind of the resonant cavity part. 5) the physical field is used to lock the sliding leg, such as locked by the magnetic field, is shown in Fig. 6.

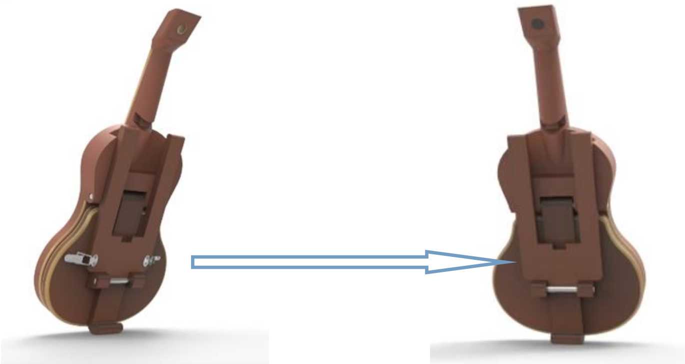


Fig. 6 The magnetic locked sliding leg

4. The hanging function solving of Ornaments chair based on scientific effects

When the guitar type hanging chair is not in using, it is hanging on the wall as a decoration, but the wall nailing a nail can affect the beauty of the room walls, there are danger as the nail bumps. How to solve this problem? For this“How to”model, the TRIZ scientific effects library is used. Through querying the scientific effects library, the magnetic field effect (E13) is used, a piece of iron is pre attached on the wall, and the guitar trype hanging chair inlaid a magnet at one end (Figure 7), so that ornaments chair can be easy to hang on the wall without breaking bad wall appearance.

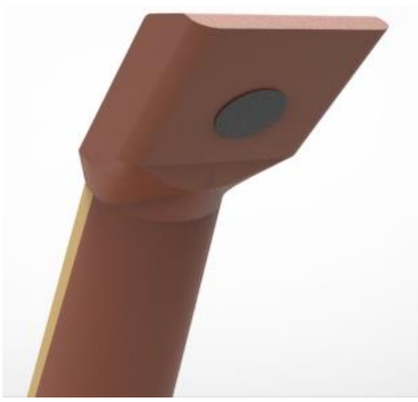


Fig. 7 Magnitic hook

5. The guitar hanging chair structure and its analysis

Based on the above analysis, the back of the guitar resonance cavity is divided to two layer, and they consist the chair folding mechanism. The positive shape is the guitar appearance (guitar head and neck, resonance) or characteristics. These structure ensures the appearance and the function of the chair, is shown in Figure 8. Further the size of guitar hanging chair is given (Figure 9), for processing it. the mechanical analysis of guitar hanging chair are given (Figure 10) and its strength to meet the requirement.

Fig. 8 The result of guitar hanging chair

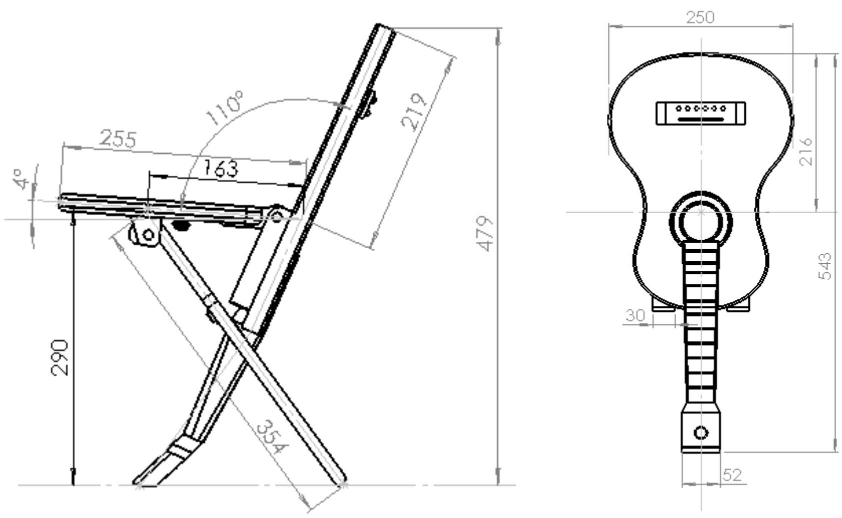


Fig. 9 The chair size

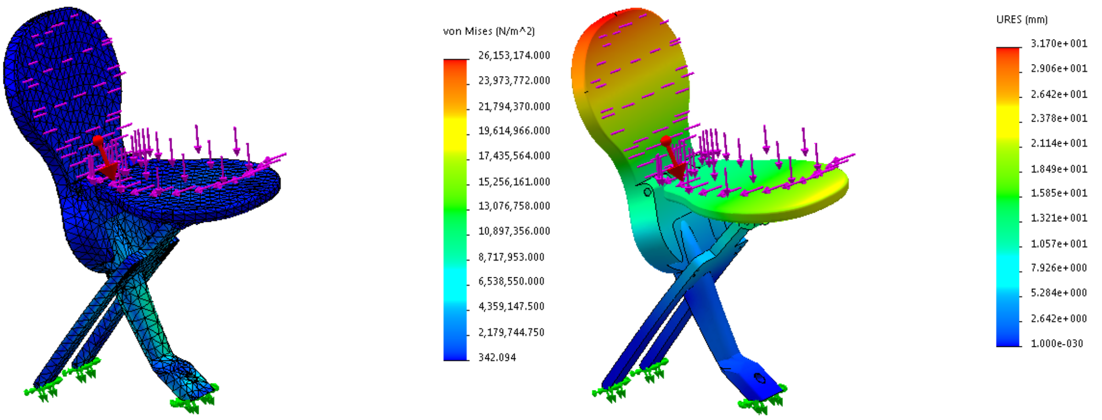


Fig. 10 The analysis of chair

Fig. 11 The 3D printed model of chair

6. Conclusions

(1) TRIZ theory can help designers to quickly find the problem solutions. In this paper, the innovative thinking tools, contradiction matrix, invention principle, scientific effects library are used to find the results of designing difficult in the process of guitar hanging chair.

(2) This guitar hanging chair combined the music elements and folding chair function, as it be used, it can be opened as a chair. When it is not in use, it can be as a decorations hanging on the wall, and the specific size given. The strength is analysed, and it satisfies the strength requirement.

(3) This guitar hanging chair is printed by 3D printer, is shown Fig. 11. If produce in enormous quantities, its practical and transferable can be considered. In the future, these factors should be studied, and this chair are analysed by function model, which bring many innovation idea for improving this chair.

Acknowledgements

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DEVELOPING CREATIVE AND CRITICAL THINKING SKILLS IN NEXT GENERATION WORKFORCE

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Abstract

The latest World Economic Forum took place January 20-23 2016 in Davos, Switzerland, with the theme "Fourth Industrial Revolution". One of the outcomes – future workforce will have to align its skillset to keep pace. Five years from now, over one-third of skills (35%) that are considered important in today's workforce will have changed. The top 4 skills, necessary for success in 2020, are:

1. Complex problem solving – a person must understand the root cause and to address the root cause rather than a symptom;
2. Critical thinking – a method of thinking in which a person questions all incoming information and even their own convictions;
3. Creativity – in a broad meaning, an ability to see something which doesn't exist yet;
4. Cognitive load management – in a world rich with information streams, formats and devices, the ability to discriminate and prioritize, to filter out what is most important.

Unfortunately, modern school doesn't teach these skills on any level. In this paper we describe our approach to developing these skills in grade school and university students.

Keywords: Skills for 21st Century, creativity, critical thinking, education

"Today, teaching creativity is more important than teaching literacy 200 years ago".
Sir Ken Robinson

1. INTRODUCTION

Educational system, as we know it today in most countries, was developed at the behest of the first industrial revolution. Literacy was necessitated by changing industrial relations. The predominately verbal forms of communication were no longer sufficient for the support of technological and business processes. Yet, the only available, at the time, industrial workforce consisted of the former agrarian workers, who were moving to the big cities in search of gainful employment at the factories since they were forced from working the land by newly introduced agricultural machinery. These people could not read, write or count. At the time, there was no educational bureaucracy, the schools were created and financed by the companies, in need of the literate workforce. In the process, the needs of the first industrial revolution were satisfied to the extreme. Grade schools produced factory workers and soldiers. Uniformity of skills and knowledge was placed at the base of the educational pyramid. Limited media resources made lecturing the main method of instruction. Technological advances notwithstanding, lecturing continues to be the main teaching method. Lately, an epidemic of standardized tests swept the world. However, even the best of tests do not test all of the important traits and skills of the future associates of the companies large and small.

At the time, it was believed that plants and factories were the most progressive and efficient production entities, thus every attempt was made to extend their practices to other areas of activity. This explains why schools, hospitals, prisons, government bodies and other institutions have many features of factory production, namely the division of labor, hierarchy and complete facelessness.

Ironically, we continue to employ Industrial Era educational system for education of the Knowledge Era workforce. To compete in the knowledge economy, it is true that our students need core skills like STEM – science, technology, engineering and math – but to thrive, in addition to these, they also require other elements, including critical thinking, creativity, leadership, global awareness, collaboration, an eagerness for lifelong learning, and the ability to deal with constant change and ambiguity. Yet, we don't teach nor test these skills. In short, we need to teach kids how to think, not what to think.

We live in a rapidly changing world, and, accordingly, life in this world is increasingly complex. Dynamism has become a characteristic phenomenon of our time. Not only is the amount of information increasing at a rapid pace, so are new technologies, and in tandem with this, public viewpoints are ever-changing as online social networks proliferate. Today, the ability to respond to abnormal situations is vital, to quickly and seamlessly immerse oneself in unfamiliar activities, to establish productive relationships with colleagues and partners, to work in a team, to take risks, to try, to be ready when the opportunity arises.

But a successful life in these conditions requires very different competencies, a different kind of education, and other technologies for assimilating the "new".

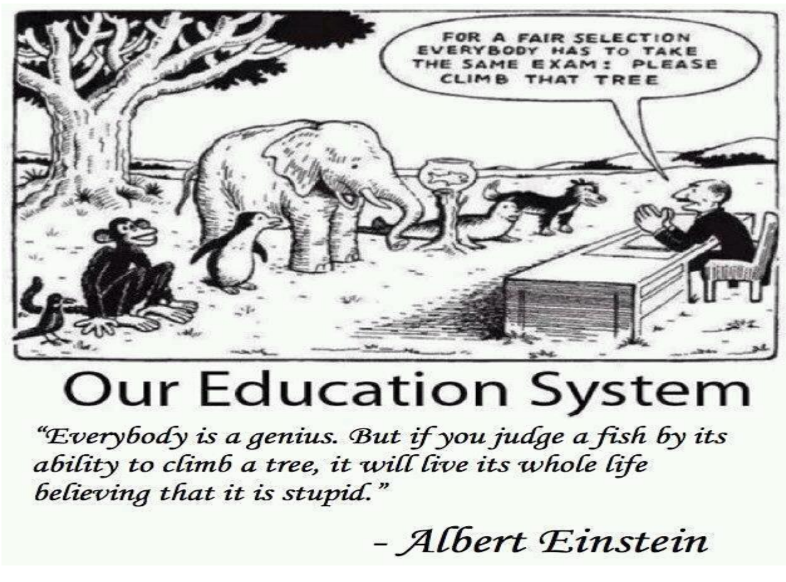

Fig. 1 Standardized testing in nature.

Personal Qualities Not Measured by Tests

CREATIVITY	SELF-AWARNESS
CRITICAL THINKING	SELF-DISCIPLINE
RESILIENCE	EMPATHY
MOTIVATION	LEADERSHIP
PERSISTENCE	COMPASSION
CURIOSITY	COURAGE
QUESTION ASKING	SENSE OF BEAUTY
HUMOR	SENSE OF WONDER
ENDURANCE	RESOURCEFULNESS
RELIABILITY	SPONTANEITY
ENTHUSIASM	HUMILITY
CIVIC-MINDEDNESS	

Adapted from Maria Montessori

Fig. 2. The things we don’t teach nor test

2. THE PRESENT SITUATION

Every country on earth, at the moment, is reforming public education. There are two reasons for it.

The first of them is economic. People are trying to work out, how we educate our children to take their place in the economies of the 21st century. How do we do that? Even though we can't anticipate what the economy will look like at the end of next week, as the recent turmoil has demonstrated. How do you do that?

The second though is cultural. Every country on earth on earth is trying to figure out how we educate our children so they have a sense of cultural identity, so that we can pass on the cultural genes of our communities. While being part of the process globalization, how do you square that circle?

The problem is they are trying to meet the future by doing what they did in the past. And in the process they are alienating millions of kids who don't see any purpose in going to school. When we went to school we were kept there with the story, which is if you worked hard and did well and got a college degree you'd have a job. Our kids don't believe that, and they are right not to, by the way.

The way we address education for areas as different as medicine, physics, computer science, law and art needs to also be very different. Some of these areas require strong theoretical understanding, others require knowledge of a vast body of work, others require constant contact with a fast-changing industry, and others require lots of practice and experience. As individuals grow and blossom in their own fields according to their own strengths, our approach to education must support them in their particular development.

An analysis of today's global trends conducted by the International Laboratory of "Education for a New Era" in 2000 revealed the key contradictions in the sphere of education. Paradoxically, we continue to use Industrial Era educational system for Knowledge Era. They relate, in particular, to the secondary education system, which by dint of its inertia and lack of effective mechanisms for change is in a serious crisis. The crisis of the educational system, first and foremost, of the grade schools, is especially acute in wealthiest countries, and is associated with a rapid drop in student motivation when it comes to education.

In the U.S., Russia, and elsewhere, the educational system has changed significantly in recent years. And yet, the influx of equipment provided to educational institutions, the use by teachers of new technologies, the appearance of new mechanisms for measuring and managing education quality has not really exerted a positive impact on the educational outcomes of students in public secondary schools. We see this in the frustration of young adults unable to forge a path in life, or even conceptualize one.

Unfortunately, we must conclude that today's educational crisis, the essence of which can be summarized as: "Life requires one thing, while the schools teach something else," has not yet been adequately addressed. Life demands that we ourselves seek out what we need to know, while the schools feed us information as a finished product, although it is obvious to everyone that the transition from the introduction to the assimilation of a large volume of information to an understanding of new types of activities – design, artistic, research, promotes the formation of such basic competencies of modern man, as "processing information" (the ability to work with large sets of poorly organized and often unreliable information, analyze it, reformulate it, apply the information to a variety of complex problems), "communicative" (the ability to cooperate effectively with other people, be part of a team), "self-organization" (the ability to set goals, plan, make full use of personal resources), "self-education" (the willingness to design and implement one's own educational trajectory throughout life, to acquire new competencies that ensure success and competitiveness), "creative" (the ability to solve creative problems that lack established algorithms in terms of a solution process).

We still educate children by batches; we put them through the system by age group. Why do we do that? Why there is this assumption that the most important thing kids have in common is how old they are. It's like the most important thing about them is their date of manufacture. Yet, any teacher can list a plethora of differences, which have nothing to do with age.

However, reality shows that although the school curriculum is designed to take age and the students' psychological characteristics into account, the focus is still on the so-called average student without any option for displays of personal interest, both as regards the content and the process of organizing lessons. At the same time, beyond the teacher's ability to see them, there is often a special group of students, children who are gifted in different ways.

Thus, our analysis of the situation indicates that most educational institutions today fail us in how they resolve individual problems, in how they socialize and instruct their students, such that there is an absence of optimal mechanisms for self-organization, both self-driven and collective action by adolescents and also upper-class students.

This is happening against the backdrop of the friction caused by contradictions in education:

- between changes in the environment that lead to changes in the values and goals of education and the existing system in which the school functions;
- between the new problems set before the school, new requirements for organizational and pedagogical conditions and the stereotypes that have developed about how to organize the educational process;
- between the appearance of a new position in the education system (tutor) and the unwillingness of teachers to change their professional and established positions to new professional competencies (supportive, moderator, facilitator, etc.);

- between the appearance of complex new educational technologies (open education technologies, critical thinking technologies, TRIZ technologies, etc.) and teachers who hold fast to traditional methodologies and standard teaching practice;
- between the new challenges faced by the family in raising their children, the new roles parents play and the complete absence of preparation for today's parents by the institution.

Then there is an issue of motivation. Learning requires motivation – an individual matter. If a group format of education is used, then how to resolve a contradiction between group and individual education requirements. If an individual format of education is used, then where the motivational resource may come from? (Teachers don't know how, students don't have the habit, and tutors are too expensive).

As a result, students are missing out on some great opportunities to develop various intellectual abilities and acquire competencies outside the scope of the subject matter — competencies that will equip them for the challenges they will face in today's world.

This is why it is vital that we teach children to perceive the world not through the eyes of an outside observer, but as active participants in shaping their own destinies. Indeed, this is in line with proposals for greater latitude in both the format and content of education. In this regard, the introduction of original pedagogical technologies to develop creative, non-standard thinking in children rejuvenates the learning process, energizing the students and increasing their desire to explore unchartered territory.

On top of this, scientific thought for some time now has recognized the need for substantial changes in educational didactics and is prepared to introduce technologies for the development of new didactics and its practical application in the family, pre-school, and grade school areas of education.

The new curriculum is based on globally-known methods for generating new ideas (from brainstorming to the theory of inventive problem solving), adapted to the education system.

The methodological framework for the development of the new didactics includes methods for generating new ideas, based primarily on TRIZ, which has been accepted around the world, having proved its productive capacity in engineering, design, inventive and project-based education. These methods are adapted to the age and general education of the children, and are complemented by interactive games, practical activities, and more.

3. WHAT'S NEXT

The three most important skills, companies are looking for when hiring new college graduates are: knowledge of the subject matter, problem solving, and team work attitude. All three are solely dependent on an individual ability to think. And most importantly, to be a divergent thinker. "Divergent thinking is creative, open-ended thinking aimed at generating fresh views and novel solutions"[1]. However, one needs to be skilled at both, divergent and convergent thinking modes, to be a skilled problem solver.

Divergent thinking isn't the same thing as creativity. We define creativity as the process of having original ideas which have value. Divergent thinking isn't a synonym, but it's an essential capacity for creativity. It's the ability to see lots of possible answers to a question. Lots of

[1] http://www.businessdictionary.com/definition/divergent-thinking.html#ixzz4ChZnkGRQ

possible ways of interpreting a question. To think not just in linear or convergent ways. To see multiple answers and not one.

These skills must be supported by:

1. An ability to see problems – is a prerequisite for problem solving
2. An ability/skill to learn – is a prerequisite for cognitive load management

Not all of the contradictions mentioned above can be addressed by our program; however, given that modern education today serves as an important means of self-realization for a person who is aware of the purpose, meaning and value of their own existence in a global world built on the principles of openness and the free exchange of intellectual and human resources, the situation can change for the better, and conditions can be created at the local level that facilitate the development of creative thinking in the next generation.

To begin with, we need to switch from curriculum, teacher, centered to learner centered education model.

Learner-centered	**Curriculum-centered**
Child centered	Teacher centered
Constructivist driven	Standards driven
Progressive	Traditional
Information age model	Factory model
Criterion-based	Norm (bell curve) based
Depth	Breadth
Thematic integration	Single subjects
Process and product oriented	Product oriented
Block scheduling	Short time periods
Collaboration	Isolated teaching and learning
Experiential knowledge	Rote knowledge

Table 1. Educational models

The switch is a must considering an enormous increase in the number of choice we face on a daily basis. These days it became a genuine open problem. Due to a huge variety of choices, selecting a trade or a place of study, changing residence and finding a new job, even making a purchase has become an open problem. And we need to learn to live in this world of enormous variety. And again we have a choice – do we continue to think linearly or develop dynamic thinking skills.

There is another fine distinction that makes all the difference. If a person is unable to cope with piling up problems, they are more and more difficult to deal with. It is common knowledge that you sow a temper and reap a destiny. If you want children to be happy and problem-free, teach them properly in accordance with their actual needs and the new realities of life. Incidentally, in this case children display no such reluctance to study as they usually do at an ordinary school.

The big question is how to properly orient education? Here are some effective remedies defined as principles in Anatoly Guin's book *Principles of Teaching Technology*. These principles build a bridge between the present and the future. They are already put into practice in today's best schools and will be just as relevant in future, though applied technically in a different way.

Basic Principles of Teaching Technology:

FREEDOM OF CHOICE

Definition

In any action of training or management, wherever possible grant the student the right to choose. Provided that the choice is always balanced by the conscious responsibility!

This can be done within the framework of the present education system. Here are just some examples of free choice, offered by world's finest educators. Give the students an assortment of tasks, and they themselves decide what problems to solve. Offers the students to choose themselves what difficult words the teacher should write on the blackboard. Gives the students only the topic and the students themselves determine which object to make and out of what material.

OPENNESS

Definition

In the process of teaching use open problems; while sharing the knowledge to show the latter's confines; confront students with problems, solutions to which go beyond the scope of the studied course.

Students have a very vague idea of the scope of their information awareness, let alone the boundaries of scientific knowledge. No wonder, they display no curiosity, without which any teaching comes down to upbringing of obedient doers.

At school students learn to solve closed problems (from point A to point B...), while life puts forward open ones. The students' interest and, accordingly, all our educational efforts vanish in the gaping chasm between them.

ACTIVITY

Definition

Organize development of the students' knowledge, skills, abilities and purports mainly in the form of activity.

While knowledge tests come down to glib answers, resembling a tape-recorder playback, while learning and reviewing are carried out in the mode of memorizing, 90 per cent of school efforts are futile and bear no fruit.

To make knowledge a tool rather than a trashcan in the backyard of the mind, students must work with it. By this we mean that students should assess, apply, convert, extend and complement it, as well as find its new connections and relationships, see it in different models and contexts.

FEEDBACK

Definition

Regularly monitor the learning process through an advanced system of feedback methods.

The more developed technological, economic, social and educational systems are, the more feedback mechanisms they contain. The pilot in-flight monitors the outside temperature, the amount of fuel left in the tanks and other instrument readings all the time. This is a must for a safe flight. The same approach is true for a successful lesson, too. During a lesson the teacher constantly monitors the mood of the students, their interest, the level of understanding and other factors.

IDEALITY

Definition

Improve education efficiency and make it cost-effective by taking full advantage of the opportunities, knowledge and interests of students.

Activity and self-organization of students increases the ideality and effectiveness of teaching and monitoring efforts of the teacher. If we manage to adapt the content of studies and forms of training to the development and academic needs of the class, the students will crave for the knowledge themselves. If we manage to agree on the pace, rhythm and complexity of learning with the abilities of students, they will feel successful and want to further sustain it. This principle implies active involvement of students in management of the team they belong to and, accordingly, in teaching each other. The teacher does not get tired while the efficiency of the teaching effort goes beyond the limit. Certain quite useful teaching techniques have been rejected in view of their low ideality: they require either too much effort on behalf of the teacher or too rare qualities of character.

Principles of teaching technology are declaratory per se. It is the methods and technologies that make them practical. But even the best teaching technique makes only half the work. The second half is the content of education. What exactly shall we teach?

What Shall We Teach?

Education is based on the transfer of knowledge, which often becomes outdated before becoming part of educational programs. It is impossible to keep up with the science.

We are facing a paradox: we must teach children to live in the world of future which is a closed book for ourselves. This paradox appeared relatively recently, when technological and scientific paradigms started to change within one generation. For example, technological paradigms of radio-design changed four times in one generation: vacuum tube – transistor – micro-circuitry – large-scale integrations.

Strictly specialized education does not meet the challenges of life any longer. A domain expert is hard to retrain and knows little if anything of related branches of knowledge. Solution of modern problems requires a systems approach, the ability to see long-term consequences. A successfully solved problem creates new opportunities. A badly solved one brings trouble. This is true not only for academic and other professional activities, but for everyday life as well.

At the present, neither higher nor secondary education meets this requirement. Large commercial companies are increasingly trying – with varied success – to solve the problem in-house. In an attempt to counter narrow specialization the US Bell System has established The Humanitarian Institute for promising managers.

After many years of educating “subjects and portions” it is hard to expect that systemic thinking will come into existence all by itself. Here is how an eminent Russian educator K. Ushinsky figuratively described the results of such education for an average student. “Concepts and even ideas are arranged in his mind in dead strings, resembling rows of swallows benumbed by the cold. Despite being very close, the swallows are yet unaware of each other's existence; and similarly the two closely related ideas can exist in such a truly murky mind for decades, failing to take notice of each other."

A renowned physicist Leo Szilard gave a very elegant illustration of the unknown. It is the space outside a ball, which symbolizes all the knowledge of the mankind. The greater the ball is the greater becomes the border area with the unknown. And each spot of this area is nothing other than a new open problem.

There is nothing that prevents saturating school education with open problems. Regular confrontations with exploratory and creative problems of unknown solutions are as critical for the development of mind as vitamins for a growing body. There are such problems in every subject and interdisciplinary area. And it is these problems that shape and develop creative intuition. After all, apart from being a nature-given talent, intuition is a specifically organized and embedded in the subconscious creative experience of solving unusual problems.

Methods of developing imagination and inventive thinking have already come to education. Here are some facts. The Young Engineers Club in Britain runs regular national competitions, publishes its own magazine. The U.S. Patent and Trademark Office initiated a special partnership PROJECT XL, designed to support the development of inventive thinking curriculum for all student populations. The PTO has also developed the Inventive Thinking Resource Directory for teachers.

Albert Einstein noted that "imagination is more important than knowledge, for imagination embraces the world". To this we would like to add: knowing how to think outside the box, that is, how to imagine, is even more important. The Theory of Inventive Problem Solving develops and puts into practice high-order thinking skills. Although this theory has already gained ground the world over, the most interesting experimental platforms for its application in education are found in Russia. Of course, these are only tiny sparks in the awakening volcano of new education but they are quite capable of sparking a flame.

However, inventive thinking development alone is not enough for success. To reach the desired goal, it is necessary to acquire teaching skills for creative work organization. This includes scheduling and time recording, ability to work with databases, creation of scientific development evaluation criteria and, of course, discipline. But discipline should be conscious and creative as well, different from the primitive implementation practice. And all this is quite feasible.

4. CONCLUSIONS

The ideal didactics means no didactics at all. A student strives for knowledge so vigorously that nothing can stop them. Without electricity they would read by candlelight.

The ideal management means absence of management while its functions are performed. Everyone knows what to do and does what he should because he wants it himself.

The future of the school is determined by neither the head ruler nor by education minister nor even by teacher. Each education process participant makes his own decision whether to keep pace with the future or turn back on it.

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FLOW ANALYSIS OF BUSINESS SYSTEMS (CASE STUDY AND THEORETICAL RESULTS)

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Abstract

The present article represents a case of the development and application of a technical and economic model for supporting usage of TRIZ tools in business. We adopted the DuPont formula as a source one. During our work, we modified it using the TRIZ concepts of ideality and flow analysis. The results of this approach are shown herein based on a specific business case as well as on the example of famous businesses. The conclusion contemplates the issues that require further studies in order to ensure that our methods can be successfully used afterwards.

Keywords: TRIZ, business development, economical factors, efficiency, product ideality, organizational ideality, DuPont model, ROA.

1. Introduction. Problem description

The idea of this article was conceived in the course of a practical corporate development business project. Our customer, a major warehouse logistics company, took an interest in TRIZ and offered us a carte blanche, i.e. the opportunity to get any information and use any TRIZ methods we needed to improve the efficiency of their company. Us, a TRIZ team, were very inspired with the prospects thereof at first, however it turned out after some time that it was too early to celebrate. The customer's business system did not actually have any technical problems. Their equipment was new, everything was working fine and the staff was well trained. They did not have any marketing problems, either. The marketing team was well acquainted with the market, good at promotions, discounts and bonuses. As the customer put it, the main thing they needed were the economic performance indicators, like profitability and returns on investments. Moreover, the customer only wanted to assess anything we suggested in terms of these values. They were not interested in innovation or inventive level. It meant essentially that the interaction between the customer and the TRIZ team required an "interpreter" for a new "language" that could be used to "translate" the customer's economic goals into the "TRIZ-language" and reformulate the solutions and suggestions developed by TRIZ into the economic results and indicators known to the customer.

Basically, we managed to solve this local issue. However, in the process of searching for a solution, we might have encountered some problems and results that are valuable both for the development of TRIZ practice in business and for the clarification of some theoretic stipulations. This article is concerned with setting forth these results and problems, as well as describing the workflow.

2. DuPont model and the TRIZ concept of ideality. Product and organization ideality.

In the process of working on our basic problem, we contemplated several economic models of the so-called managerial accounting, in the search for one that could serve as an "interpreter" from the language of economy into the TRIZ language, and back. After several iterations, we chose the “DuPont model”, developed by the DuPont company in the 1920's /1/, /2/. 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).

Let us briefly recollect the basic logic of the DuPont model. The main formula that economists use to assess business efficiency is as follows:

$$ROA = Profit / Assets, \qquad (1)$$

where *ROA* is “return on assets”;

“*Profit*” is the profit from transactions during a specific period;
“*Assets*” means the sum of assets that ensured the corresponding profit.

The ROA value can serve as an indicator of business efficiency. If the returns on assets excess the average market/industry value, then the business is efficient; if not, it is not. The problem with using the ROA "as is" consists in the fact that it is unclear which parameters should be handled to increase it and how it is done (e.g., it is evident that a parameter like Profit cannot be controlled directly).

To transform a financial formula into a business development toolkit, t was changed in DuPont as follows (dividing and multiplying the source version by the Sales figure):

$$ROA = Profit/Assets = (Profit/Sales) * (Sales/ Assets) \qquad (2)$$

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 particular, they were also known to our customer. To make a forward move and start using TRIZ tools, the team had to do something in addition, since the (2) formula, although instrumental, still had nothing to do with TRIZ.

We finally managed to achieve essential progress through using the concept of "ideality", one of the key ones within TRIZ. First, "ideality" is one of the most potent tools for qualitative development, efficiency and competitive ability boosts. Second, in terms of warehousing logistics, we reached the ideality indicator in a simple and evident way, since the technological operations in warehousing are quite simple, consisting either in transportation or in manual operation (inspection, selection, re-packing), or in plain "storage".

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";
"∑ F", for the useful functions of the product;
"∑ C", for the sum of "requital factors", the expenses for using the functions.

Like this, the (3) formula is an analogue of the Sales/Cost economic indicator, 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).

Thus, the first hypothesis consisted in the equivalence of the following formulae:

$$I = \sum F / \sum C \sim \text{Sales/Cost}^{2} \qquad (4).$$

The second part of the (4) formula can be obtained through a series of simple rearrangements of the DuPont formula:

$$\text{Profit/ Sales} = (\text{Sales} - \text{Cost})/\text{Sales} = 1 - 1/ (\text{Sales/Cost}) \qquad (5)$$

and, if we set Sales/Cost as "product ideality", or I_p, then the (5) formula and the first part of the DuPont model shall look like

$$\text{Profit/Sales} = 1 - 1/ I_p \qquad (6)$$

where the general logic of the DuPont formula and the ideality increase logic are maintained: this multiplier grows along with I_p, meaning that increasing the ideality of the product results in sales profitability growth. Thereby, we have eventually obtained the first desired correlation between the TIPS tools and economic models assessing development.

However, it turned out much harder to interpret the second component of the DuPont formula (Sales/Assets), also known as "assets turnover". In this formula, Assets stand for the monetary value of the entire company's property (balance sheet). 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 terminology /3/, to formulate the following hypothesis. In 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 "functionality" (Sales) have been provided using the available resources (Assets) within a given period. 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 (and we may call it "organizational ideality", I_{org}). In this case, assets are the resources that were available to the company; they are essentially similar to ∑C in the (4) ideality formula. This value shows which resources or assets the company used

[2] *For exact correlation, it should be noted that the ideality formula (3) is abstractly measured as "functions" and "requital factors", while the Sales/Cost proportion has a monetary expression.*

to manufacture all the required product volume (suggesting that Sales ~ ∑F). 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 TRIZ tools and economic business indicators.

As a result of our rearrangements, the DuPont formula now looks as follows:

$$ROA = (1 - 1/I_p) * I_{org} \tag{6}$$

where I_p is product ideality

I_{org} is organization ideality.

3. Flow models in use: hypotheses and cases

The next important step in the rearrangement of the DuPont model was taken after applying the (6) result to setting and solving tasks related to the customer's business development. There was however a difficult moment caused by the following: no doubt that economic parameters like Sales or Cost have a "flow" nature because they are a "conventional" unity of a certain complex of isolated objects and operations (performed by both staff and machines). Evidently, there is no "physical" linkage between "yesterday's" and "tomorrow's" products stored at the warehouse (things come and things go; different products belong to different owners). Neither is there a direct correlation between the operations that the staff members perform (one thing today and another thing tomorrow). The concept of "flow" as a way of representing different things in a unified way is a chance to interpret these heterogeneous elements as something united, a "conventional system". This is why we can see Sales and Cost figures related to a time period. The Assets value is a different matter. From the accounting point of view, it stands for the "average value" of the assets during a given period; in standard resources logic, it means their average amount. Assets are traditionally interpreted in a static manner, usually represented as a "one-off picture" of the very same warehouse, shelves, loaders every day. We did not find a way to imagine this resource within the same logic of "flow" as we did with the other components of the DuPont formula.

However, we managed to solve this issue using the TRIZ toolset called "flow analysis" /4/. We used it to re-interpret the Assets of the warehousing facility in question as one of the elements, to-wit, the "channel". Metaphorically, Assets (resource) can be imagined as a “riverbed” upon which the flow is moving. The riverbed serves to organize, confine, and direct the flow, thereby forming its significant features.

Another important step we took was turning the representation of assets from static into dynamic: we found out that the resource is not the one-off (instant) capacity (amount) of assets but their aggregate amount during the analysis period (same as the one used to determine Sales and Cost in the DuPont formula). Here is an example of applying this on a warehouse example: the everyday "capacity" of the warehouse (number of storage cells) multiplied by the number of days within the analysis period makes the actual "resource". I.e., the resource is not 3,000 physical cells within the warehouse but 3,000 * 30 = 90,000 cell*days. This is the maximum capacity, the full resource that is not to be exceeded to prevent the system from being "flooded" if the flow overruns its bed. Again, we can metaphorically say that in this "flow" interpretation, the resource (Asset) moves in time, while the flow of goods and transactions moves both in time (along with assets/resource) and in space (through various points of the resource/asset, e.g. from acceptance to storage and then to dispatching area).

Based on the aforesaid hypothesis, we have formulated two main ways of increasing the "organization ideality", *Iorg*:

$$\text{Var2} = (\sum F\uparrow)/(\text{Assets} = \text{const}), \tag{7}$$

increasing the deployed functions (Sales) on the same assets amount as before.

$$\text{Var1} = (\sum F = \text{const})/(\text{Assets}\downarrow), \tag{8}$$

decreasing the use of assets to perform the same functions (sale volume).

In TRIZ, the (7) procedure corresponds to the "bottleneck analysis" tool, intended to discover the bottlenecks preventing the flow from moving unobstructed. Here is an example of this kind of bottlenecks at the customer's warehouse. The storekeeper had to choose a certain storage unit on a specific shelf (within the warehousing area intended for bulk products so that the storekeeper had to find and take the necessary objects from among the other ones in the cell). First, this was very time-consuming; second, in order for the stockman to find the necessary object quickly, one had to place less objects on a specific shelf. The standard way of solving this issue is getting more storage shelves and engaging more staff members in selecting and batching, resulting in the growth of the $Sales \sim \sum F$ useful function but also in the growth of the involved Assets; this, in the long run, does not give any qualitative growth of the Iorg value. The TRIZ team suggested the following nonstandard solutions for this bottleneck:

(a) make the shelves inclined to increase the effective surface for storage (a shelf inclined by 30 degrees ensures a 15% longer effective surface, a resource that is virtually "free", meaning that the required assets and expenses required to do this are really insignificant when compared to its subsequent benefits)[3]. In this case, we used a resource-based approach, "making shelves bigger".

(b) provide the shelf (storage shelf) with a camera that takes a picture every time that an object is put on or taken from the shelf and then sends it to the Warehouse Management Information System. Then, a staff member who needs to take something from a shelf can see a picture showing the place where the object is located (e.g. on a tablet PC screen) and pick it up right away. The barcode system can also be relied upon. This solution results in an increase of the assets (complicating the WMIS), but these expenses are manyfold compensated by the benefits, since it gives the opportunity to store products in a cell (on a shelf) in several layers, which, when a standard method is used, is equivalent to the multiplication of the cells number. In this case, the "copying" method and the "self-searching system" resource-based approach have been used.

[3] *To prevent things from rolling down to the lower part of the shelf, its surface should be made corrugated or covered with non-slip coating.*

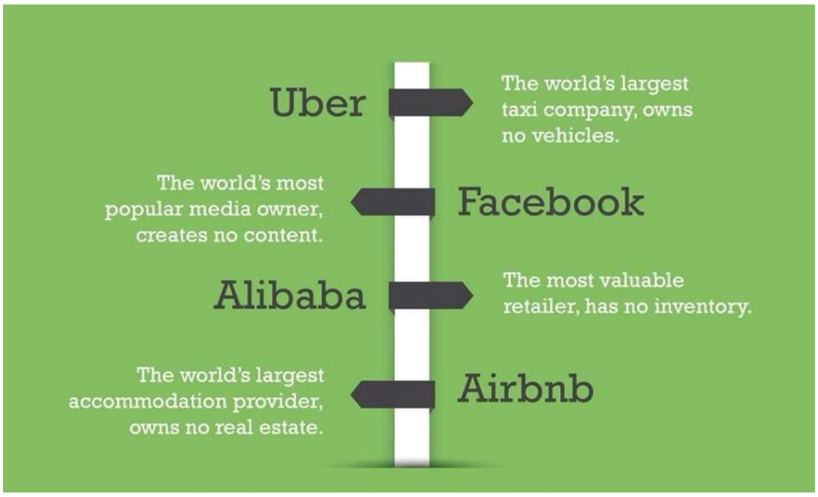

Fig. 1

The (8) procedure is, in TRIZ terms, equivalent to the "trimming" operation of cutting off unnecessary and redundant functions/assets that are not used in current operations. The TRIZ team was not asked to handle this type of problems by this customer, however we would like to illustrate the validity of the approach by picture (Fig. 1).

This is a list of major companies from the Sales point of view that however do not have a list of assets that is common for this kind of businesses. In terms of "organizational ideality" I_{org}, they have a much higher Sales/Assets ratio than their competitors because they have found a way to handle the flow without any rigid boundaries, through arranging the "channel" in a different manner (in terms of TRIZ flow analysis). We believe that the key element here is the "copying" method, where each "real" object exists basically as its copy within an IT system and only appears "physically" while there is a paying demand (a specific Uber taxi car).

4. Summary. Conclusions and investigation prospects

As already stated before, our theoretic survey was performed along with a real-life business project and was subject to respective timeframes and resource limitations. The TRIZ team managed to do what was required: find, formulate and solve technical problems using the TRIZ approaches, ensuring that the initial and end points of the project (targets and results, respectively) be displayed in economic indicators. However, we realize that this result alone does not yet give enough reasons to generalize and circulate our approach and method (e.g. to use TRIZ systematically to handle business cases). Apart from more case studies, we should also perform a deeper survey of theoretic stipulations and hypotheses brought forth during our work.

These are some of the problems that require further studies:

A) Clarification of the concept of "function" used in TIPS. We encounter two different interpretations using the same term of function as "an action changing an object's properties" (in cost-and-value analysis) and "usability / consumer property" (in ideality formula);

B) Clarification of the concept of "values" as used in Main Parameter Values analysis for example, in connection with and in relation to the concept of "function";

C) Describing the difference of "specific" and "conventional" technical systems. The first ones are usually understood as "natural objects" (e.g. machine, production line), while the second ones are the result of certain "conventional" systematization or linkage ("flow", "sales", "business"). Due to this, the procedures of system analysis are different for these systems. In the first case, component and structural analysis come first, followed by flow analysis and more. In the second case, it is the flow that "constitutes" the system, therefore it should be studied prior to the detection of other components and linkages; moreover, such components and linkages eventually depend on the choice of the flow;

D) Allowance for the special aspects of using physical and monetary measurements in the DuPont model;

E) More detailed elaboration of the DuPont model, particularly with regard to different types of sales, costs, and assets;

F) Simulation of the company's performance at different stages of its lifecycle, with regard to different ways of increasing product and organization ideality;

We are determined to continue our studies in this field.

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GENRICH ALTSHULLER AND PETER DRUCKER: ALTERNATIVE APPROACHES TO SOLVING PROBLEMS. COMPARATIVE ANALYSIS

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Abstract

In the twentieth century, fundamental changes were introduced in two of the most prevalent areas of human intellectual activities: management and capability to invent.

One change common to both was the transition from an empirical, intuitive activity based on inspiration to a systematic, scientific approach. Such an ordered approach to management was developed by Peter Drucker, while Genrich Altshuller proposed a methodology to solve complex technical problems and create new inventions. The main objective of this paper is to identify and describe the similarities and differences associated with the two theories as proposed by their founders.

Today, such research remains vitally important for the following reasons:

- Managers are showing a growing interest in systematic ways of developing creative solutions, and
- TRIZ researchers and developers are actively working to adapt proven TRIZ tools in order to solve various business problems, including managerial ones.

In order to perform a comparative analysis of the theories established by G. Altshuller and P. Drucker, the following list of criteria has been created: the main object of the research, the methods of analysing and processing initial information, the format of methodological recommendations, approaches to proliferating the knowledge obtained, and the target users of the methodology.

The main results of the comparative analysis are discussed in this paper in order to aid the further development and adaptation of TRIZ tools for problems specific to management. The paper also summarizes recommendations concerning problem formulation, the process of problem solving, resource identification, and implementation of the solutions developed.

Keywords: TRIZ & management, systematic approach to innovate

1. Essential Attributes of Innovation: Creativity and Management

Before there can be a discussion about its attributes, the term "innovation" should be defined yet again. There are thousands of versions of this definition available - if we type "innovation definition" in Google, it will bring about 383,000,000 results. Extensive research on this topic has been presented recently by Nick Skillicorn [1]. He contacted fifteen of the world's leading innovation experts and asked them three questions:

1. What is your definition of "innovation"?

2. What mistake do companies often make when they talk about innovation?

3. What simple thing can a company do to change their conversation / perspective about innovation?

The answers obtained by Skillicorn greatly surprised him: "Even amongst the group of industry insiders here who teach and author books on innovation methodologies, case studies and thought leadership, there was a huge variety between the responses" [1]. Next, he analyzed the responses in order to find the most common themes and come up with the ultimate definition of innovation.

Some of the definitions and general thoughts proposed by the experts as well as the ultimate definition proposed by Nick Skillicorn [1] are presented below:

"The application of ideas that are novel and useful. Creativity, the ability to generate novel and useful ideas, is the seed of innovation but unless it's applied and scaled it's still just an idea". David Burkus

"An innovation is a feasible relevant offering such as a product, service, process or experience with a viable business model that is perceived as new and is adopted by customers". Gijs van Wulfen

"There can be no innovation without commercialization". "Move from idea generation to product commercialization". Mike Shipulski

"Creativity is thinking of something new. Innovation is the implementation of something new". Paul Sloane

The ultimate definition of innovation developed by Skillicorn based on a thorough analysis of what the fifteen experts said [1] is: innovation is executing an idea which addresses a specific challenge and achieves value for both the company and customer.

Skillicorn's analysis [1] can be depicted graphically as shown in Fig. 1 below.

The authors believe this definition is both practical and instrumental. In fact, this final definition, as well as some from other experts, contains two fundamental terms:

- "execution" which is associated with management, and

- "idea" which is associated with creativity and the ability to invent or identify/develop new things.

It is also important to note that some innovation experts mention the need to employ systematic methods to create successful innovations: "A simple thing companies can do to change the conversation about innovation is to train it. Set up formal courses teaching systematic methods of innovation like SIT and TRIZ. Teach people about idea management, idea selection, and pipeline development. In other words, see innovation as a competency like leadership or ethics". Drew Boyd [1]

Peter Drucker is known as the founder of modern management whose principles are implemented in all types of organizations whether commercial, social, or governmental. Genrich Altshuller created TRIZ, a methodology which allows people to invent and develop new ideas. Both Drucker's management fundamentals and Altshuller's TRIZ appeared at about the same time – the middle of twentieth century – and are still being developed by their followers. Both of these theories marked a transition from an empirical, intuitive activity based on inspiration to a systematic, scientific approach.

Now, in an era of innovations, TRIZ and management can significantly enhance companies' ability to innovate.

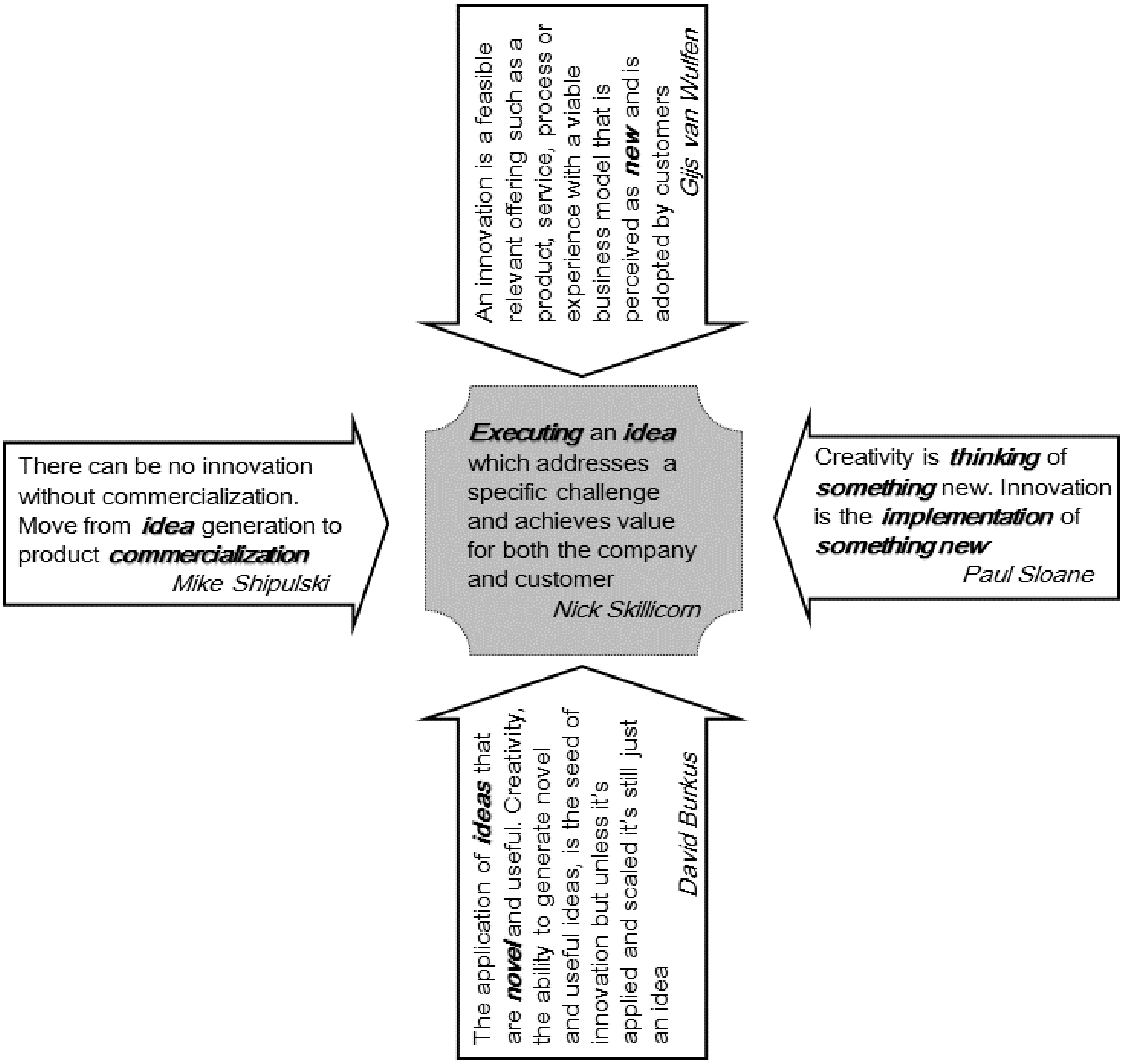

Fig. 1. The ultimate definition of innovation based on the opinions of innovation experts

Below, the authors have summarized the similarities and differences associated with the two theories, as proposed by their founders. Based on this summary, recommendations for the further development and adaptation of TRIZ tools for problems specific to management can be formulated. In addition, the authors will discuss how to improve the process of formulating and solving problems, identifying resources, and implementing the solutions developed.

2. Comparative Analysis of the theories established by G. Altshuller and P. Drucker

In Table 1 below, TRIZ and management theories have been compared using the set of criteria proposed by the authors.

Table 1

Comparison of theories established by G. Altshuller and P. Drucker as proposed by their founders

Criterion	G. Altshuller	P. Drucker
Objectives	- Controllable evolution - Every problem should have its solution	- Support for decision makers - Long term programs of development
Area of applications	Creative imagination for anyone, anywhere, anytime	Generally people oriented
Information basis	- Patent collection - Case studies from seminars	Systematization of leaders' experience
Features of theories	- Resolving contradictions, instead of compromising - Adapting ideas from other areas (including scientific effects) - Trends of evolution; empirical forecasting	Socrates style: "I cannot teach anybody anything. I can only make them think."
Typical format of tools developed	- Multistep algorithms, e.g. ARIZ - Detailed recommendations - e.g. Standard Solutions, pointer to effects	Questionnaires specific to area of company's interests.
Main approach to solving problems	In-depth analysis of initial problem and understanding its fundamental causes	Identification of outer opportunities - "Results are obtained by exploiting opportunities, not by solving problems."
Formats of theory proliferation	Seminars and workshops for solving actual problems and collecting examples / case studies for further seminars	Personal and comprehensive interviews with leaders of large corporations
First users	Engineers, researchers - developers of ideas	Thought leaders of companies, corporations
Extended area of usage	Overall enhancement of creativity - The Theory of Creative Personality Development	- Personal development - Management of non-profit organizations
Influence on professional community	Introduction of a new occupation - Professional Inventor	Establishment of a new category of professionals: Knowledge Workers

As can be seen from Table 1, Altshuller's and Drucker's theories do differ in many ways: different objectives, tools, first users, etc.

Both theories, however, deal with solving problems, albeit in different ways:

- TRIZ, as introduced by Genrich Altshuller, is about developing creative ideas (inventions) to address technical problems,

- Peter Drucker's theory focuses on identifying and exploiting opportunities.

Current mainstream TRIZ development is largely focused on increasing the efficiency of the analytical tools that allows identification of "right" problems to be solved. That is because of the paradigm shift: "we don't need to spend time and effort for solving any problem; instead we should focus our effort on identifying and solving problems that lead to innovation." In keeping with this updated paradigm, TRIZ can also be adapted for problems specific to management. Adapting TRIZ this way will give managers a way to control the process of solving technical problems in their organizations.

3. Modern TRIZ and its adaptation for problems specific to management

As shown above, creative ideas and management are two attributes of any innovation. TRIZ experts are able to generate numerous creative ideas, but the question is "What is the one winning idea we can use to create an innovation?"

Another important note is that currently about 80% of ideas/solutions come from information searches. That is why so much attention has been focused on developing tools that make the information search more efficient. To date, the Function Oriented Search (FOS) introduced by Simon Litvin [2] is one of the most efficient problem-solving tools for identifying existing technologies/ideas from areas of science and engineering remote from that of the planned innovation.

Nowadays, vast amounts of data are available. An interesting approach to data analysis has been proposed recently by McKinsey [3]: "Traditional data analysis is based on what information you have, advanced analytics on what information you need" (see Fig. 2).

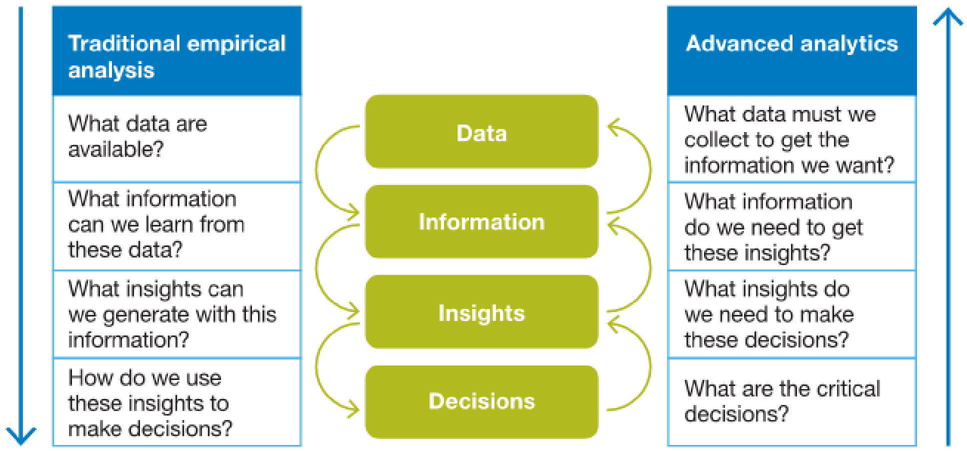

Fig. 2. Comparison of approaches for information analysis

According to this approach, we must first identify an opportunity or make a decision. Then, ideas or information should be collected to support this decision.

4. Conclusions

The main conclusion based on the comparison presented in this paper is as follows: there are no critical differences between the two approaches, that is, the "search for opportunities" and the "search for ideas" are quite similar. The first approach can identify a general, potential direction, while the second approach supports the practical implementation of a selected direction. TRIZ is characterized by a set of proven methods for solving technical problems that appear within a direction/opportunity. In other words, TRIZ supports the part of innovation responsible for "new ideas"; management is more about execution of ideas.

Originally, TRIZ was created for engineers and focused on technical problems only. That is why it has well-developed procedures and algorithms for solving problems. Drucker's approach was oriented to elite managers and is based on questions that are formulated very precisely and then discussed in detail.

Nowadays, for innovative activity to be successful, the work of managers and engineers must be all-encompassing. Therefore, a combination of the two approaches - TRIZ and management - leads to win-win methodological developments that can be used at different levels in organizations.

Having performed this comparative study, the authors now believe in the relevance of further methodological developments in adapting TRIZ for management. There are, of course, a few methodological developments in this area by other TRIZ practitioners (see, for example, [4], [5]). The research presented here may be used as a starting point for the systematic development of a combined TRIZ-Management approach which can accumulate and integrate the methodologies now available.

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INNOVATION DESIGN OF FOLDING BICYCLE BASED ON TRIZ THEORY

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Abstract

According to the analysis of the technology system evolution model of modern green transportation bicycle, the paper found the existing problems of the bicycle in current market: After riding, inconvenient to place and carry the bicycle; poor user experience with strenuous and time-consuming features as well as the conflict between ideal final result and product cost. This paper planned to start with the innovation principle of TRIZ theory, using cause and effect as well as system functions to analyse. For mechanism design, the paper used mechanics substitution, changed the operation and another dimension, and redesigned the folding mechanism; for product cost and ecological design, the paper used the ideal result of resource analysis method, so as to better meet the requirements of practical procedure. Applying multiple ways of 40 principles of invention, it aimed at increasing product diversity as well as achieving a better user experience, looking for various solutions, and the paper ultimately confirmed the improvement direction through comparing the products' idealization and feasibility assessment, so as to gain preferred plan, that is, using the new design plan of metamorphic mechanism, which possesses the advantages like simple structure, strong property, light and portable, two-wheeled parallel after folding, easy to ride and carry, less space and so on. It satisfied the development direction for the bicycles to tend towards green revolution, portability, light weight and fashion. Moreover, the paper also proposed future intelligent application and safety indicator system as the application prospect of modern bicycle with practical promotional value.

Keywords: TRIZ, folding bicycle, ideal final result, innovation design

1. Introduction

Bicycle is one of the most popular means of transportation [1], it is flexible, portable, eco-friendly. Especially environmental pollution, energy pinch, traffic congestion is becoming increasingly serious [2], which afford the advantages of bicycle inject new vitality into life. As China's big population density, the shortage of land and road resource, hence bicycle is indispensable now or in the future, and research on bicycle will also continuously innovate and progress [3].

2. Technology system evolution theory analysis on the evolutionary process of bicycle

The eight laws and patterns of technology system evolution (as shown in Table 1) [5] guide innovation and development of products, based on pattern 3, pattern 6, and pattern 8 of the technology system evolution, the evolutionary process of bicycle is analyzed as follows:

Table 1

Table 1. Eight Laws of Technology System Evolution and Patterns Technology System Evolution

The Laws of Technology System Evolution	The Patterns of Technology System Evolution
Law 1：Law of technology system evolution S-curves	Pattern 1：Technology follows a life cycle of birth, growth, maturity, decline.
Law 2：Law of enhance idealization	Pattern 2：Increasing Ideality.
Law 3：Law of subsystem imbanlance evolution	Pattern 3：Uneven development of subsystems resulting in contradictions.
Law 4：Law of dynamic evolution	Pattern 4：Increasing dynamism and controllability
Law 5：Law of evolve to super system	Pattern 5：Increasing complexity, followed by simplicity through integration.
Law 6：Law of subsystem harmony	Pattern 6：Matching and mismatching of parts.
Law 7：Law of evolve to microcosm	Pattern 7：Transition from macrosystems to microsystems using energy fields to achieve better performance or control.
Law 8：Law of evolution to automation	Pattern 8：Decreasing human involvement with increasing automation.

Altshuller, Henry. 1994. The Art of Inventing (And Suddenly the Inventor Appeared).

According to pattern 3 and pattern 6, the uneven development of the bicycle system leads to the emergence of conflicts, which have initiated the innovative form of bicycle [4]. There were no pedals in the original design of bicycle, by stepping on the ground and making friction, cyclists drive the front and the rear wooden wheel rotates, and drive the bicycles move straight with retroaction, among which the contradictory conflict is that the bicycles move too slow. In order to solve the conflict, the front wheel is made bigger than the rear wheel, and the pedal is installed on the front wheel, the speed is directly proportional to the diameter of the front wheel, due to the uneven development of the front and the rear wheel, the size difference is thus intensified, resulting in the instability of the bicycle. To solve this conflict, designers began to study the transmission system of the bicycle, equipped it with chain and sprocket, the application of chain transmission system not only enhances the stability of the bicycle, but also increases its speed. However, the chain transmission system of the chain-bicycle is composed of crank, sprocket, chain, flywheel, rear axle, but all the parts are equipped in a loose fitting, the whole transmission system is large space occupied and exposed outside, which even can cause the chain to take off and break. In order to further solve the problem, non-chain bicycle appears, with the help of gear transmission, shaft and gear transmission system, each parts are closely integrated as a whole without loose situation appearing, the total transmission is little space occupied. The mechanical efficiency of gear transmission is over 98%, the mechanical efficiency of the chain transmission is only 95%, however, non-chain bicycle has not become the mainstream of the market. According to model 8, decreasing human involvement with increasing automation, affords the electric bicycle and electric folding bicycle success and show more advantages, but for the consumer market, expensive cost and energy consumption reveals its greater defects. The prospect of folding bicycle application is broad, and the folding bicycle will have larger development space.

Nowadays popular folding bicycle has the following design styles: Beam-folding Mode, A-bike Mode, Internal folding Mode, Uniaxial Support Folding Mode. Different applicable situation and the demand of different consumers promote different types of products; various folding designs all have their features as well as disadvantages. However, they all have the following disadvantages: folding method is complex, time-consuming and laborious, folded shape is irregular, two wheels are not parallel, inconvenient to carry, applicable occasions are restricted, riding comfort is low and easy to get tired with low security.

3. The system analysis of existing folding bicycle

The Several typical folding ways all have technical contradictions in different aspects, some main points are listed as follows, considering from the view of causal analysis:

(1) To fold the beam from the middle directly, then the whole body is represented as triangular radiation type, the front wheel and the rear wheel cannot fold parallel to each other, the space cannot be used effectively. As the wheels is not parallel, and cannot roll on the ground, which leave man to make it move forward, hence it is not convenient to carry, such as the Beam-folding Mode which is widely used (Figure 1).

(2) To fold the parts of bicycle only occurs in the same plane, the front and the rear wheels cannot be folded parallel to each other, and the folding way determines that the size of the wheel diameter is limited, because if the wheels are too big, the volume of wheels cannot change significantly after they are folded, so riding stability and comfort cannot be guaranteed, such as the Internal Folding Mode and A-bike Mode (Figure 2).

(3) Some folding ways can afford the front and rear wheel folded to a plane, but the shafts of the front wheel and the rear wheel are special unilateral support, represented as cantilever beam structure, the shearing force is relatively large, easy to wear and damage (Figure 3).

Fig. 1. Beam-folding Mode

Fig. 2. Internal folding Mode and A-bike Mode

Fig. 3. Other modes (Strida folding Mode)

The folding methods of folding bike are generally to fold and overlap the wheels and the frame as far as possible to certain space, and the current existing folding methods are generally to fold in a plane, such as Beam-folding Method which can only fold all the stuff in plane YOZ, the Internal Folding Method and the Front-parts-folding Method which can only fold all the stuff in plane XOY. All the above folding methods cannot use space effectively. Even though the front and rear wheels can be overlapped together, the front and rear axles are all cantilever structure, the structure is not stable, and the service life is short, hence all folding methods have their own shortcomings. Therefore, conclusion can be made that it is inconvenient for users to carry folding bicycle and the user experience is bad, the reasons are the limitations of key mechanism design and thinking mode of folding status changing.

From the view of system function analysis, the essential function of folding bicycle is to "downsize", to make it more portable. Therefore, the bicycle size should downsize and be more portable on the premise of not reduce the riding satisfaction.

4. Folding bicycle innovative design on TRIZ

4.1. Design folding bicycle system based on TRIZ innovative theory

On the aspect of mechanism design, the technology part of the entire product is folding mechanism. Therefore, the ideal result is replacement of parts or the entire system, principle change, and to redesign the key folding mechanism; on the aspects of production cost and the ecological design, new design should not completely get rid of traditional design, to meet the standard production mode and the consumer acceptance, based on the ideal use of resources (to ensure the consistency of the general part as far as possible), consumers' better comfort can be better met.

On the basis of ensuring the original components as far as possible and TRIZ innovative theory, to redesign the folding mechanism, following analysis, finally to find the most suitable, enforceable innovative ideas (Figure 4). Based on the best use of resource, the following principles can be used: principle 12 Equipotentiality, the design level of product material and general components is not upgraded or reduced, only the working principle of mechanism is changed; principle 27 Inexpensive, short-lived object for expensive, durable one, low-cost objects replace expensive objects to better adapt to the automatic production, to do improving design based on national standard parts; principle 16 Partial or overdone action, to solve the problems better and quicker, to reach good effect based on the best use of original resource. On the basis of changing principle of the ideal result, the following principles can be used separately: principle 17 Moving to a new dimension, to change present movement mechanism of the single dimension plane into motion mechanism with multi-dimension plane, to increase the activity as well as to ensure the stability; principle 35 Transformation of the physical and chemical states of an object; principle 36 Phase transformation, to change the motion mode of folding bicycle, especially for the key motion parameters and reliability; principle 33 Homogeneity, to choose and design more suitable folding mechanism, other products of the same, similar design can be referred to, so as to upgrade the mechanism; principle 25 Self-service, better consumer experience is offered after riding in order to better meet the needs and satisfaction of different people, moreover, the bicycle should be easily portable without laboriously taking it after riding ; principle 32 Changing the color, the final product should be represented as a variety of comfortable colors, to meet the requirements of people from different levels, increase the diversity of products, so as to make it a perfect product which can adapt to the modern market [6].

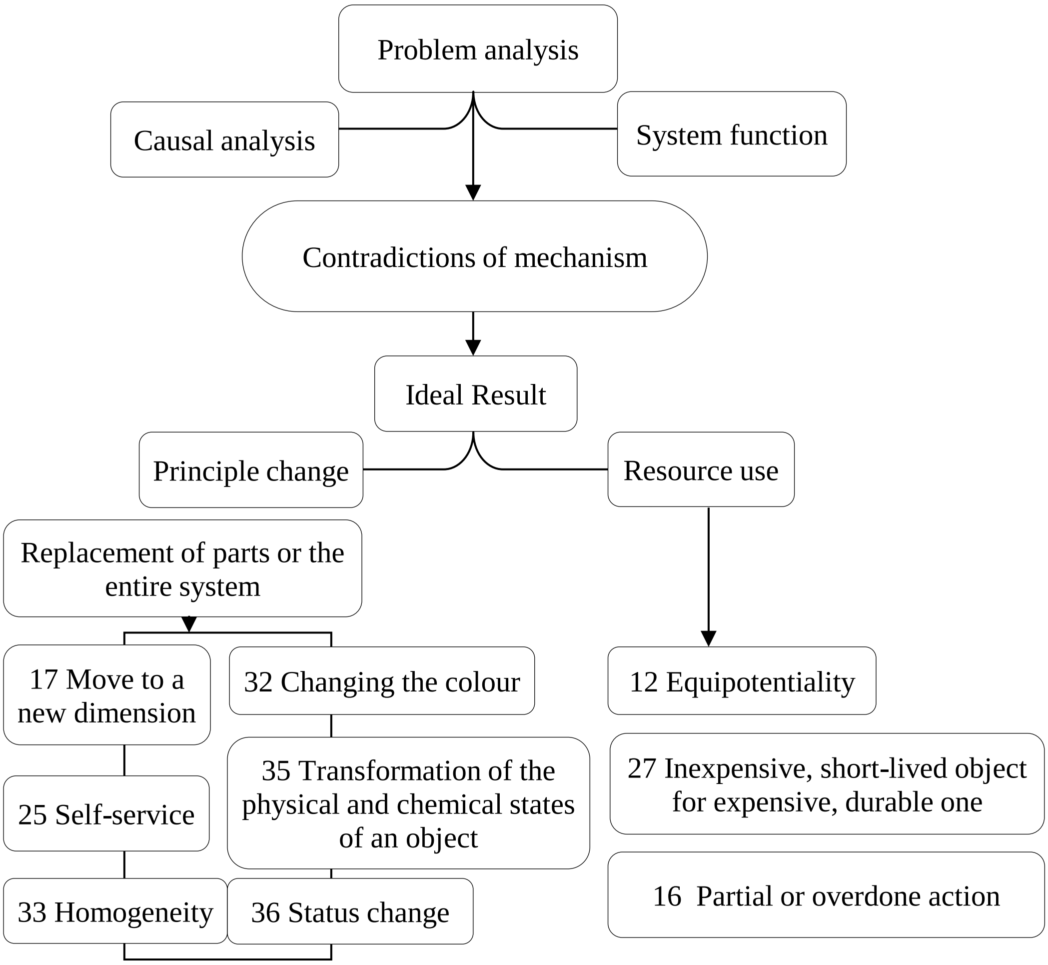

Fig. 4. Using the method of TRIZ analysis to solve problem and innovation design

4.2. Arrangement and evaluation of technical innovation design

(1) Design integrated by mechanism and electricity:

Electric folding method: there are two main folding points, the first is the frame folding, introducing the folding principle of the pole of folding umbrella, the structure is novel and easy to operate. Frame folding process: first pull the pulling plug, pull out the internal plug, and then fold it, then the frame can be folded. Figure 5 shows the effect of the frame folding. The second is the seat post folding, introducing the connection method of the rotating thread sleeve, it is easy and convenient to install and fold. The effect of the seat post folding is shown below. Seat post folding process: rotating the thread sleeve to make the upper and lower pole separated, then seat post can be folded. After folding the electric folding bicycle, the overall effect is 1.2 meters long and 0.5 meters wide. But the battery volume cannot be too large in this folding way, which leads to the decline in the endurance capability of electric folding bicycle; in addition, after electric bicycle is folded, the circuit system will be necessarily impacted, hence the circuit system demands more accuracy, and the production costs increase; the two rear wheels are not easy to carry and deposit. The scheme has the disadvantages of complex structure and high quality, if the upgrading and replacement of other suitable materials are expensive, it is not suitable for mass production.

Fig. 5. Electric folding bicycle

(2) Design of complete mechanical structure：

The method of metamorphic mechanism (Figure 6): many crafts, decorations, and flat box formed by folding mechanism in life is flexible and can be efficiently folded, such as magic toy bouquet of metamorphic mechanism, and folding umbrella of flexible metamorphic mechanism, automobile sunshade umbrella with the design features of combined folding of metamorphic mechanism and narrowing and broadening characteristics, the large satellite antenna and solar panels in the field of aerospace are all typical folding metamorphic mechanism, the above typical examples are formed by using the metamorphic mechanical principle, so as to better realize mechanism of folding and unfolding. As metamorphic mechanism can be applied in many occasions at different working stages, and by a state to another state, in order to present different types of mechanism and to achieve the functional requirements, the topological structure of metamorphic mechanical and mechanism of freedom should be changed. Then in the folding scheme, this method can afford the bicycle folding mechanism at work a configuration, and other configuration when it is folded in the X-Y plane, even in the X-Y plane, no freedom can be found, it is able to move in other planes such as the Y-Z plane. These are the characteristics of the metamorphic mechanism, the traditional mechanism cannot achieve automatic reconstruction and combination of this component. Moreover, the conversion feature of the configuration of metamorphic mechanism makes the bike be able to convert from working state to folding stage without extra mechanism, additional folder and fastening devices, thus simplifying the number of the mechanism of the folding bicycle, no need to worry about losing the function of traditional folding device by repeating use, increasing the life span of the folding mechanism bicycle. The folding mechanism of bicycle designed by metamorphic mechanism has no special requirements on the wheel size, and if the wheel is too big, the mechanism cannot be folded, which cannot happen. The volume of the folding mechanism can still be small. Similarly, using the traditional front and rear axle support on both sides, which cannot affect the riding stability and the service life of shaft. In summary, the folding mechanism of the metamorphic principle scheme has more practical value and development prospects.

Fig. 6. Folding bicycle with metamorphic mechanism (self-made picture)

5. Conclusion

The evolutionary rule of technology system in TRIZ, the evolutionary pattern of technology system, the close combination of innovative design principle and the design process of the bicycle will all make the creative design of the bicycle easier to implement in the future. The new design scheme of the metamorphic mechanism is adopted, which has the advantages of simple structure, portability, light, the paralleled plane after folding, occupying small space, which all meet the future bicycle tends to be more green, portable, light, fashionable. Combined with the Internet information technology, the application of intelligence, and safety indicator system, more innovative design with practical value can be made. Evolutionary theory of technology system cannot only be able to predict the development of technology, but also to present the predicting results, and realize the structure of products. As evolutionary pattern of technology and the rules have the ability to transfer, which afford any products innovation guiding significance.

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LEARNING TRIZ AND USIT BY TACKLING REAL-WORLD PROBLEMS - A CASE STUDY

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Abstract

The Theory of Inventive Problem Solving (TRIZ), although very powerful, has the reputation of being difficult to learn and master. This factor alone may inhibit the growth and spread of TRIZ, the powerful systematic innovation methodology.

Some students of TRIZ have sought to ease the teaching and learning burden of TRIZ. Combining TRIZ with Unified Systematic Inventive Thinking (USIT) as an introductory combined course is but one way to simplify the teaching of TRIZ thinking and principles. This should reduce the learning effort required by new students and encourage the uptake of TRIZ.

Four questions arise:

Question 1: "Does combined training dilute the essence and power of TRIZ?"

Question 2: "Does combined training raise the TRIZ learning burden of candidates?"

Question 3: "Will combined training increase the growth and acceptance rate of TRIZ?"

Question 4: "Which combined training approach will foster the spread of learning and using TRIZ?"

In the paper, the author firstly relates and compares TRIZ practitioner course levels 1 to 3 to an introductory systematic innovation course offering which combines TRIZ and USIT approaches. The author then works through the four questions from his own learning journey and that of others. Useful insights are generated from the case, and many of these could contribute to improving the spread and uptake of Altschuller's ideas.

Keywords: Learning, Teaching, TRIZ, USIT, SIT, Real-World Problem Solving, TRIZ Derivative Approach as Intermediary.

1. Introduction

In this introductory section, the reader is provided with a brief background to the systematic innovation methodologies discussed, the circumstances leading to the paper, and the structure and purpose of the paper.

1.1. Background

Genrich Altshuller developed the fundamental tools of TRIZ, by analysing author's certificates and patents in Russia [1]. He synthesised and organised his research findings to create the original components of TRIZ. He was always keen to find a tool that would integrate or unify the many components of TRIZ [2].

Many of Altschuller's students learned and used the existing TRIZ components to good effect. Other users of TRIZ expanded it to incorporate additional inventive or complimentary methods such as Six Sigma [3] or to move beyond engineering to the arts, such as culinary arts [4], to business [5] [6], to organisational management issues [5], and to specific industries, for example to construction [7]. A third group of TRIZ users shared Altshuller's desire for simplifying TRIZ, and Advanced Structured Inventive Thinking (ASIT) [8], USIT [9] and other integrative approaches were initiated. A fourth group wished to teach and propagate TRIZ [8] [9] [10] and many of these also had an interest in the integration of TRIZ knowledge and its approach to invention.

1.2. How the Paper Came About

The author's sale of his information technology business, combined with his experience in developing, presenting and growing training, prompted him to learn TRIZ in order to teach and propagate it. His fifteen years of experience in teaching confirmed to him that 'the why' together with the real-life contexts of training material, provokes student interest and commitment to learning the content. The training duration is also subject to context. Pressures on organisations place an economically attractive three day course length constraint on introductory level training in many countries.

1.3. Paper Structure

In section 2 the origin of USIT from its TRIZ roots is briefly given. The International TRIZ Federation (Matriz) teaches and curates TRIZ course levels and the knowledge and competencies required per level. The knowledge and competencies for Matriz levels 1 to 3 [12] are compared and contrasted with the author's combined (TRIZ-USIT) training course content presented in six modules [11]. Real world example problems in the combined course are presented to students for their impact on learning in both TRIZ and USIT approaches. One such example is presented in this paper.

In section 3, four questions, chosen to generate insights, are answered based on the author's experiences and from the experiences of others who have been involved in combined TRIZ-USIT approaches [8] [9].

The four questions are: Firstly, "Does combined training dilute the essence and power of TRIZ?" Secondly, "Does combined training raise the TRIZ learning burden of candidates?" Thirdly, "Will combined training increase the growth and acceptance rate of TRIZ?" And finally, "Which combined training approach will foster the spread of learning and using TRIZ?"

The purpose of this paper is to generate learning and discussion from insights into the combined TRIZ-USIT training approach. The hope is that one or more of the insights will foster the uptake rate of TRIZ training, and accelerate the spread of TRIZ practice and benefits throughout the world.

2. Learning TRIZ versus Learning Combined TRIZ-USIT

2.1. TRIZ Spawns USIT Via SIT

After the fall of the Berlin wall in 1989 and end of the cold war, many students of TRIZ emigrated across the world and formed companies and alliances, of which a good number taught TRIZ to interested Western organisations and individuals.

Ronnie Horowitz, after learning about TRIZ undertook a doctorate with the aim of integrating and simplifying TRIZ [8]. These efforts led to the Advanced Structured Inventive Thinking (ASIT) approach and training course.

When the Ford Motor Corporation was taught ASIT, Dr. Ed. Sickafus, repurposed the training to meet the practical needs of the engineers and workers at the Corporation and USIT was born [9]. USIT differs from TRIZ in that it does not **require** the use of software or databases, or complex procedures and table look-ups. This is not the same as saying that such activities are disallowed or unfruitful. The USIT process integrates many TRIZ principles and some direct methods through a scientific and systematic approach which is careful to include mechanisms for creativity. Drawing problems and possible solutions as systems, using focus, abstraction, reflection, and calling upon inventive principles and ideality thinking, fosters creativity. In addition, root cause analysis, attribute space-time dependencies, functional and multi-screen thinking, and the 'closed world' and 'particles' diagram approaches to ideal solutions, blend analysis and creativity with thinking.

The USIT practitioner is encouraged to document flashes of inspiration as 'plausible conceptual solutions' throughout the process. The USIT practitioner's mind is primed with a sharp definition of the problem, directed through a sequence of inventive thinking tools, and used to progressively document, incubate and integrate plausible conceptual solutions into many inventive solutions of which one or two are particularly relevant to a current problem or needed solution. Earlier plausible conceptual solutions either shape a solution, or may be used as a source of later or related solutions.

USIT uses an easy-to remember, three-step process to produce results. Step one is 'Problem Definition', where the aim is to get to a **well-defined** problem statement; Step two is 'Problem Analysis' where the problem is viewed in its system context. Trimming or removing objects which are not directly related to the problem, provides sharp focus. Step three is 'Problem Solution', where additional plausible conceptula solutions are added to earlier solution ideas that were generated in the first two steps.

Sickafus emphasizes that, although the USIT approach has three main steps and each of these has a handful of substeps, the **content** of the steps and neither the order, nor the structure of the steps, is of most interest. USIT practitioners are encouraged to go back to previous steps and to iterate as often as needed to refine or progress ideas to achieve an innovative result. Because this is done without reference to TRIZ tables or software programs, the users of USIT are able to move rapidly through problem situations to plausible conceptual solutions. Their mental capacity and agility improves with experience and, because of fewer administrative distractions, they can speedily reach the systematic and innovative solution of complex problems.

2.2. Comparison of TRIZ and USIT through the Combined Training Modules

Figure 1 and its accompanying explanations, compares and contrasts the TRIZ required knowledge and competencies with the content of each of the author's six combined course

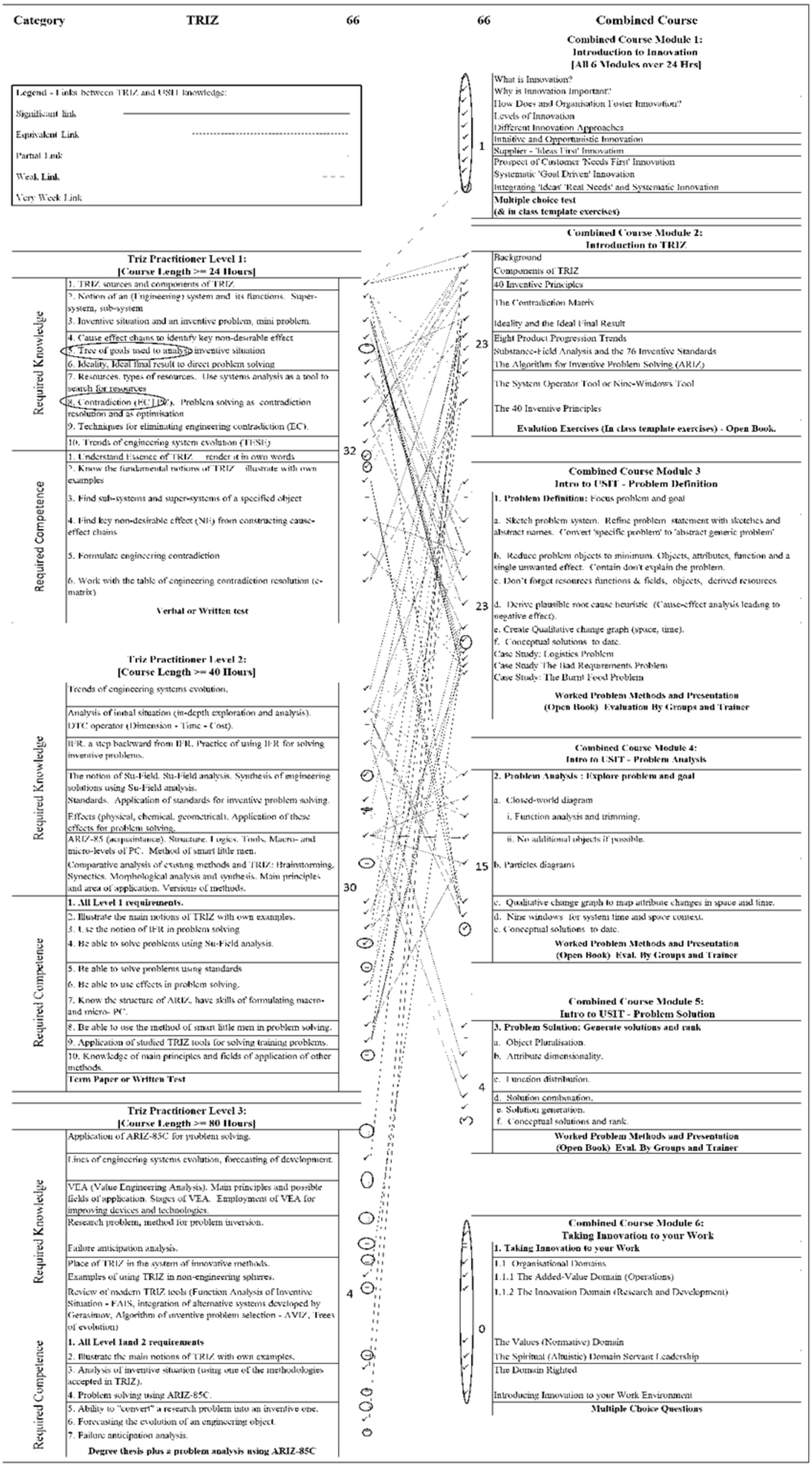

Fig. 1. TRIZ Practitioner Levels Related to Combined Course Modules

modules [11]. Detailed mapping of the relationships between the TRIZ levels 1 to 3 [12] and the combined course content of modules 1 to 6 was undertaken and is presented for reference.

In particular, 61 of 66 relationships are established between Matriz Practitioner levels 1 **and** 2 knowledge and competencies, and combined course modules 2 to 5 detailing the TRIZ components overview, and the USIT problem definition and analysis phases respectively.

The links between TRIZ and the combined course content entities are categorised as: 'Significant'– there is an easy-to-see, direct relationship; 'Equivalent'– less easy-to-see, yet still direct relationship; 'Partial' – some degree of connection, and then two 'Weak' and 'Very weak' relationships.

The number of relationships ending at each Matriz level and each module number are shown as larger numbers on the inside edge of each labelled level or module. Small circles or ovals, associated with each TRIZ level, highlight content that is poorly related to, or absent from the combined training modules. Small circles or ovals on the combined training course side indicate content that is **not** found in the TRIZ required knowledge or competencies of Figure 1. Small tick-marks throughout show content that is of interest, whereas small open squares indicate missing relationship to information which in Matriz levels 1 and 2 is important, but is less of a concern for Matriz level 3 as this is generally considered to be too advanced for an introductory course. Before attempting to answer and extract insights from the four questions detailed in section 1, it will be useful for the reader to see how a 'real-world' problem is 'solved' firstly using a TRIZ approach, and then using a USIT approach.

2.2. The Logistics Problem - Solved by TRIZ and then by USIT Approach

The logistics problem arrives. The owner of a logistics company recently experienced a third truck overturning on a corner despite the driver keeping to the speed limit. He asks you to prevent the problem without slowing down the trucks. The trucks carry boxes of variable sizes and weights.

Using TRIZ, the ideal final result could be 'use no truck service – e.g. outsource it' or, local ideality, could result in 'corner fast but remain stable' while making use of cheap or available resources. Important resources are moving-object dimensions (height, width, length, and speed), driver, load, gravity, side forces (centripetal forces, wind, static, and kinetic friction between road and tyres).

Available system resources were identified and sketches and a cause-effect analysis were completed. The key technical contradiction was identified 'corner fast but remain stable'. Speed and length (height) were referenced in the contradiction matrix. Recommended inventive principles '13 – do it in reverse', '4 – Asymmetry', and '8 – Counterweight' were used in coming to a solution.
'Do it in reverse and asymmetry' brought to mind solutions to lower height of the centre of gravity of the load when driver loads the boxes on the trucks and tie the load down to prevent side force asymmetry of a shifting load mass. 'Counterweight or anti-gravity' suggested the solutions of using lighter loads. The load configuration solution was deemed the best.

USIT approaches the same problem in a three main steps, namely, 'problem definition,' 'problem analysis,' and 'problem solution'. A more detailed description of USIT approach is provided than the summary description of the preceding TRIZ approach, as the TRIZ practitioner may be less familiar with USIT.

Problem Definition (refer to Figure 2)

USIT Problem definition starts with the innovator drawing sketches and abstracting terms. Next the key non-desirable effect is identified from a 'root cause heuristic' diagram. Then progressive sketches are used to produce a 'well-defined problem statement'. This tight definition will later be used to identify the minimum key objects, attributes, and functions that contain the problem. Plausible conceptual solutions are generated and recorded **in each of the three main steps**.

Identification of resources in the system and its related super- and micro-systems are included in the sketches and a 'root cause heuristic' diagram. The key non-desirable effect is then further analysed against identified attributes associated with root causes in a 'qualitative change graph'. This graph is used to explore attributes and their dimensions and effects on the non-desirable effect.

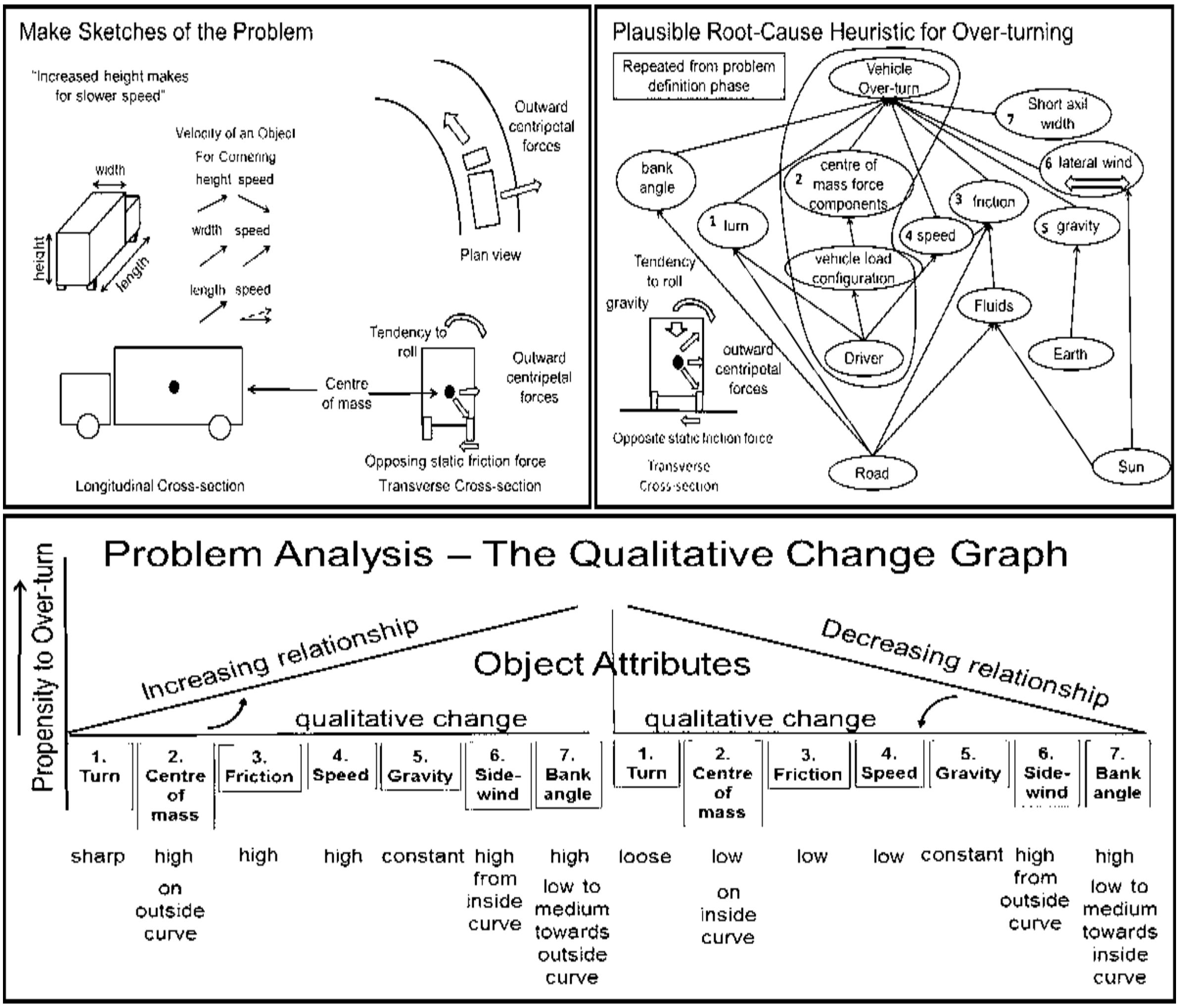

Fig. 2. Clockwise – sketches of problem, root causes, and qualitative change graph

Problem Analysis (refer to Figure 3)

Convergence on a solution begins with the drawing of a closed world diagram. Often the ideal result is placed as the key outcome at the top of the diagram. This helps to reformulate the problem positively, now as the ideal solution result, therefore 'instability', the non-desirable effect becomes 'stability' the ideal result in the closed world diagram.

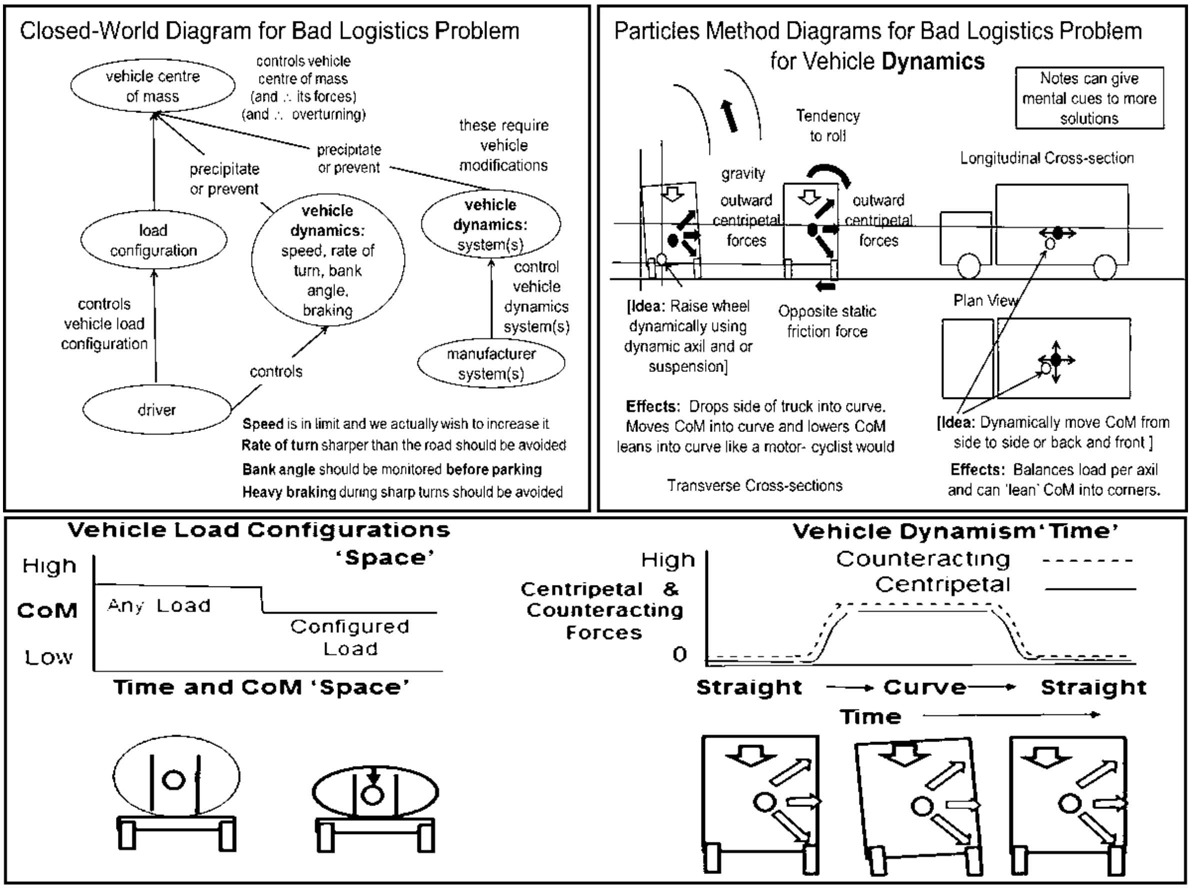

Fig. 3. Clockwise – closed world diagram, particles method, attribute dimensionality in space & time

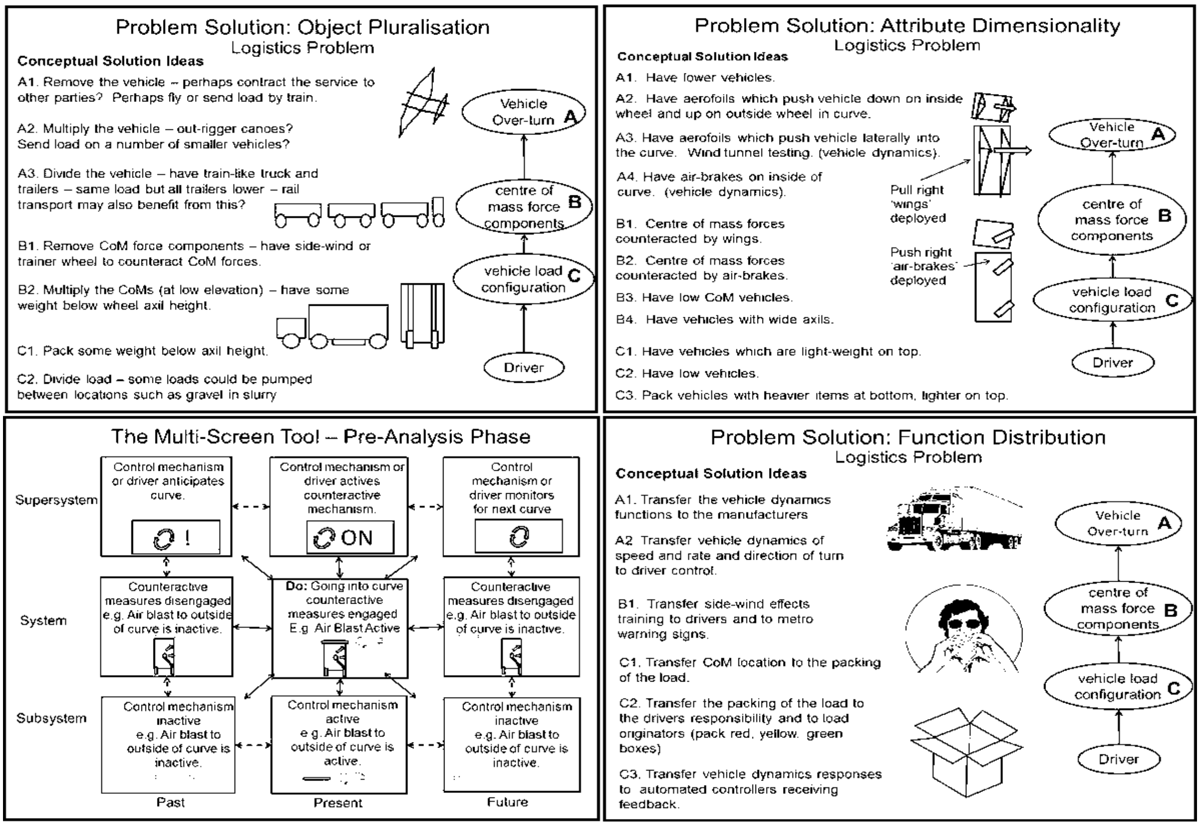

Fig. 4. Object pluralisation, attribute dimensionality, function distribution and multi-screen

The particles method (named in TRIZ ‘smart little people’), allows creative analysis of the problem and allows functions to be considered without the psychological constraints of the practitioner being limited by the existing system. Space and time characteristics of important attributes are considered.

Problem Solution (Refer to Figure 4)

The creative processes of object pluralisation, attribute dimensionality (attribute space-time related changes), and function distribution within the system, super-system and micro-system are then used to generate solution ideas. Figure 4 depicts a sample of these processes. Solution combinations are then explored for function, sequence, space, time, structure, and spirit. Finally solution generalisation explores other possible market uses for the solutions, or specific aspects of the solutions against a hierarchy of root causes. The plausible conceptual solutions from the whole USIT process are then ranked and the best one or two ideas are selected for prototyping.

Notice that USIT does not concentrate directly on the 40 individual inventive principles, nor on the contradiction matrix, yet its solution processes are able to create inventive solutions with high ideality.

3. Insights from Four Key Questions

3.1 Does combined training dilute the essence and power TRIZ?

Combined training material in a three day course definitely reduces TRIZ teaching and learning time from the Matriz level 1 material. However the combined course modules complement much of Matriz practitioner level 1 **and** level 2 material. The course therefore shows the essence and power of TRIZ over an increased content scope (two Matriz levels).

A good example of how TRIZ and USIT complement each other comes from a discussion of the 40 inventive principles. Module two of the combined training course allows teaching of the first five inventive principles with worked practical examples. Students are then invited to derive results for similar practical examples for principles 6 and 7. Furthermore the combined course provides all 40 inventive principles and their sub-categories with engineering, business and IT or service industry examples. Finally, module 5 of the combined course teaches problem solution by ‘object pluralisation’ or ‘multiplication’. Guidelines for this again emphasise some of the inventive principles as multiplication by zero equals ‘Take out’; by two or more is ‘Merging’; and by a fraction is ‘Segmentation’.

So it is with other components of TRIZ. Indeed the nature of the combined training presentation is that TRIZ is emphasised as extensive and powerful. Comments like, “TRIZ takes a long time to master, but this is well worth the effort” and, “Let’s be aware of the main components of TRIZ and how they work at a high level so that if we ever get stuck, we know where to go”, ensure that TRIZ components are given significant attention during the course.

The combined course showcases the power and essence of TRIZ and therefore does not necessarily dilute it. Matriz level 2 elements, such as the trends of system evolution, and more advanced problem solving, and the combined course’s providing of examples other than only using technical examples, motivates candidates and shows more of TRIZ’s power.

The combined course places TRIZ as a systematic innovation approach among other systematic and commonly used innovation approaches. It also provides the work context of systematic innovation and provides specific growth steps for individuals and organisations who wish to innovate.

In conclusion, teaching time and learning time for Matriz level 1 is diluted. However the benefits of USIT complementing TRIZ at Matriz levels 1 and 2 include: 1. Deepening an understanding of TRIZ and alternative usage of TRIZ-based components; 2. Expanding TRIZ beyond engineering problems; 3. Removing some of the software and table-look ups, and de-emphasising su-field modelling and the 76 standards in the introductory course; and 4. Providing innovation and individual and organisational contexts for TRIZ. These differences suggest that the benefits of using the TRIZ-USIT combined course as an intermediary to teach TRIZ, may not only enhance the essence and power of TRIZ, but might also increase the contextual perception of TRIZ and the engagement footprint of TRIZ in candidates' minds.

3.2 Does combined training raise the TRIZ learning burden of candidates?

Combined learning and training of TRIZ and USIT does add to work volume and therefore physical work burden of both teachers and candidates in the short term. However the combined course provides a first view of TRIZ, USIT and systematic innovation in general, and in its cross-industry, cross-discipline and individual and work contexts. This creates excitement and a psychological recognition in candidates, that engagement and hard work will provide useful skills. The course channels this excitement by allowing time for groups to solve three candidate-sourced problems.

Candidates are also taught in various training styles to cater to for learning modes during the combined course: 1. Individual reading of course slides and notes; 2. Trainer presentation, and question and answer opportunities; 3. Individual evaluation assignments completion – open book day-to-day assignments and tests; 4. Groupwork discussions, contributions and results; 5. Individual presentations of group contribution tasks; 6. Critiquing individual presentations of own and other group members against checklists; and 7. Self study of course materials.

In conclusion, the combined course increases the volume and intensity of candidate work and engagement required. The learn-by-doing, learn-by-teaching (presenting), learn-by-self and learn-by-group and trainer approach, provides multiple and different channels of learning. Taken together, and given that learning channels are reinforcing, this therefore makes the work seem like less, and class sessions seem faster. The increased range and utility of the content provides significant motivation to candidates which eases their burden of learning.

3.3 Will combined training increase the growth and acceptance rate of TRIZ?

Darrel Mann has recognised four types of TRIZ candidate response to TRIZ training [13]. In essence the four responses are: 1. Those who believe or act like TRIZ is not for them; 2. Those who like a subset of TRIZ and adopt it into their own way of doing things; 3. Those who engage pragmatically with TRIZ, learning what they need, when they need it; and 4. Those who are passionate about TRIZ, and obsessively pursue singular knowledge goals, often to the exclusion of a wider view.

The author has found it useful to ask course candidates an introductory question which can be used to shape the way they engage with the course. The question is, "Why are you here?" It can be followed by "Do you have to be here?" and other questions to elicit responses. It's quite difficult for candidates to disguise an aversion to the course, and open and honest responses are encouraged and then responded to by the author. Benefits of what they will learn and objections are openly answered in the light of course content they will learn. This sets the right course tone and expectations, but it is not an infallible technique.

For those who do not respond positively to the author's opening questions, the next step is to place them into small groups which generally include positive candidates. They must now work together at close quarters with at least two other group members. Most surrender their reluctance, and even start to enjoy the course. It is important for the trainer to monitor individual and group dynamics and to remove obstacles to learning where these are detected.

Mann [13] has suggested that educators should rather let the candidates adapt TRIZ to themselves than forcing them to adapt to TRIZ. I agree with this, but add that where they are at variance with important TRIZ principles, a discussion of the TRIZ standpoint encourages debate and learning, while allowing space for the candidates to derive their own conclusions.

Finally it may be useful for candidates to be asked "are there any products, services processes, or management interventions in their organisations that could be done better?" This helps candidates to think how they might improve work situations. Mann's second or third categories of user response do not need much added trainer attention. The fourth response, the obsessive pursuit of narrow goals by candidates, is already somewhat subverted by the introductory course, which encourages candidates to pursue a curious and experimental approach to systematic innovation and of course to TRIZ and its components.

In conclusion, catering for the different learning modes of candidates, overtly setting course expectations, and remaining positive and open in ones' course delivery, while supporting candidates in their learning, are methods the author has used to good effect in increasing the uptake of new skills.

3.4 Which combined training approach will foster the spread of learning and using TRIZ?

Arguments for presenting an introductory TRIZ-USIT combined training course have been put forward. In the author's advanced five day course training time allocation, TRIZ to USIT is presented in the ratio of 3.5 to 1.5 days respectively, and similar training styles and benefits are expected as a result of pursuing the approaches in parallel. Some exercises however, will be expected to exclusively reflect TRIZ and modern TRIZ, while others will concentrate exclusively on USIT.

In the author's ICT previous training discipline, the uptake of training courses has been fostered by regular monthly or quarterly special interest groups, six-monthly, or yearly conferences, freely and widely available standards, and a detailed course content syllabus for each training level, but with some latitude in course design. An additional factor of high influence has been the gradual industry-awakening to the importance of the discipline for those working in operational, management, leadership or consulting roles of specific jobs.

The attractiveness of jobs and strength of demand for jobs in innovation is an important factor to be clarified, monitored and encouraged. To this end **clients of innovation** should be strongly supported and encouraged to share their own experiences of TRIZ and innovation at industry events. At an organisational level, innovation should be overtly addressed and supported by senior management and all personnel should be encouraged and supported in pursuing innovation. Recruitment practices should select for innovation competencies in addition other employee criteria.

4. Conclusions

Combibed TRIZ-USIT training does dilute the time that learners spend on learning TRIZ during courses, but if a combined course expands thinking about innovation practices and adds material which both motivates and encourages candidates, the essence and power of TRIZ itself are not diluted.

The actual volume of training content is increased in a TRIZ-USIT combined course. However the wider combined TRIZ-USIT content scope, varied training channels, and numerous channeles of learning, can change candidate perceptions about the effort required, accelerate learning, and actually ease the candidate's burden of learning because of intrinsic motivation.

The combined training course can make training more acceptable and enjoyable to candidates if the correct course expectations are set and if candidates are encouraged to work on problems important to them, and can achieve significant results. Candidates who might have taken on very narrow goals of learning might be encouraged to explore and experiment more if the course is presented in an open way, with more reasoning and choice encouraged.

Finally global, local and organisational events which showcase and promote TRIZ and innovation, and encourage clients to share their TRIZ experiences and support employees in pursing TRIZ, can be effective in growing TRIZ interest and benefits. TRIZ training standards and a carefully crafted syllabus for each TRIZ course level also raise the profile and professionalism of the TRIZ training and create demand. Introductory combined TRIZ-USIT courses may be particularly suited to introducing TRIZ, and may act to 'prime the pump', with context, group dynamics, and a fuller vision of what is to come, and an experience by candidates of what can be achieved by growing TRIZ skills.

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LEARNING TRIZ THROUGH LITHOGRAPHY-ELECTRONICS CO-EVOLUTION

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Abstract

TRIZ has been introduced to SMEE in 2008 with the help of TRIZ expert Dr. YongMou Liu from Global Engineering Technology (GET) Co. There hasn't been much further progress, for several reasons, until the end of 2013; when SMEE management asked system engineers to learn TRIZ and apply CAI software in real projects. There are still many problems with further promotion of the methodology beyond basic training, considering tight project pressure. One of them is the lack of consistent examples to illustrate the seemingly unrelated aspects of TRIZ.

This paper illustrates innovation cases actually realized in lithographic-electronics industry, treating the two as a co-evolving tool-object pair. We collected training examples from various sources, highlighted contradictions, and demonstrated how TRIZ principles can be used. Heuristics of solutions are shown to support the evolution-revolution cycles according to Moore's Law. In authors' opinion, these kinds of training cases have many advantages being systematic, consistent, and relevant to system engineers because these cases are real and closely related to their daily work.

Keywords: TRIZ training, Moore's law, tool-object co-evolution, evolution-revolution cycles

1. Problems of learning TRIZ

Founded in 2002, SMEE is a high-tech company engaged in design of photolithographic equipment used in semiconductor related industry. This equipment operates like a large high-precision camera that can transfer a circuit pattern from a photo mask (a quartz plate containing the master copy of microscopic integrated circuitry) to a wafer (a thin slice of silicon or other semiconductor material on which chips are made).

Beginning in the 1960s, photolithography has played an important role in the fabrication and mass production of integrated circuits in the microelectronics industry.

The Main Parameters of Value in photolithography is image resolution, overlay and productivity (aka. throughput); these three requirements have internal contradictions. (See Fig.1)

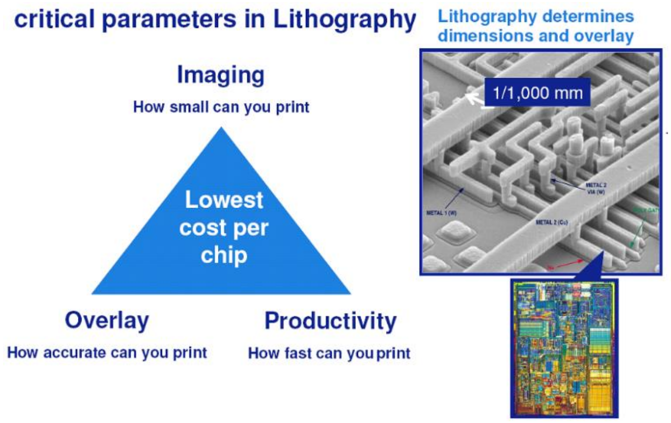

Fig.1 Contradictions in photolithography

TRIZ had been introduced to SMEE since 2008 with the help of TRIZ expert Dr. Liu from GET Co. Several system engineers in SMEE were excited to think that some day in near future, they could innovate like an inventor but some had doubts. Things are not simple after attending lectures given by Liu; there are at least these problems listed below:

1. Why the concept "contradiction" is so powerful that it could be used to solve my particular problems?
2. Is there any ways to learn TRIZ efficiently as well as effectively?
3. How can SMEE accelerate the learning process?

The answers to the first two questions are obvious from the lectures given while the last one is not. Because systems engineers are adults, their own way of thinking inertial to solve there problem can not be easily changed. Besides, all the engineers are under the high pressures of project deadlines, if the innovation cases aren't related to their daily work, they are not interested in innovation cases that show the TRIZ way of thinking.

The leaders in SMEE began taking action at the end of 2013 when they realized that only by increasing the innovation ability of engineers can we improve competitiveness of the company. That is, in order to attract more engineers to teach themselves after basic training, SMEE should build some facilities to accelerate the learning process, e.g. to build an intranet knowledge base filled with innovative cases actually realized in lithographic development industry.

These historical cases must have interrelated connections and have clear development thread between them that reflect the core of TRIZ concept like contradiction formation, evolution-revolution cycles, S-curve, development stages and trends etc. While these innovation cases are all recorded in patents, we set out to organize them in a way that presents them like exciting stories.

2. Organizing innovative cases

Semiconductor industry already has many collections of cases according to 40 principles e.g.[1]. These examples do not have enough information about problem context and emerging contradictions, and all to choose single advantage factor against a single disadvantage factor, however recent industry requirement are becoming more and more complex (e.g. performance, productivity and reliability etc.), single parameter tool may not fit for using, so that there is no interesting story to tell. Besides, these kinds of innovative examples are not related to each other and not so attractive to engineers.

In order to reflect the real history of lithography, we collect information from industry conference papers and depict the overall trees of evolution and organize the innovation cases according to different evolving routes (see Fig.2). In every innovation case, we analyse the problem from emerging contradictions, idealistic and multi-window analysis.

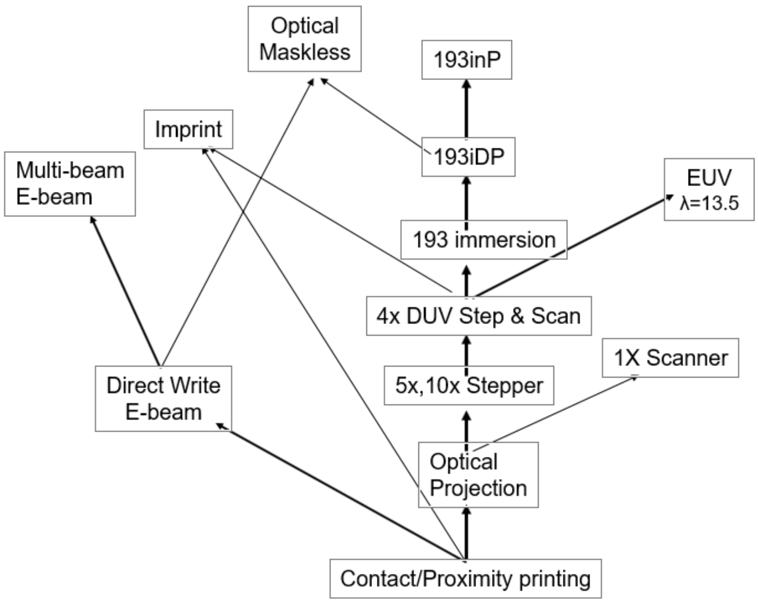

Fig.2 Evolution tree of lithography

2.1 Introduction of exposure process

The fabrication of an integrated circuit (IC) involves a great variety of physical and chemical processes performed on a semiconductor (e.g. silicon) substrate. In general, the various processes used to make an IC fall into three categories: film deposition, patterning and semiconductor doping. Films of both conductors (such as polysilicon, aluminum, tungsten and copper) and insulators (various forms of silicon dioxide, silicon nitride and others) are used to connect and isolate transistors and their components. The basic principle of photolithography is as follows:

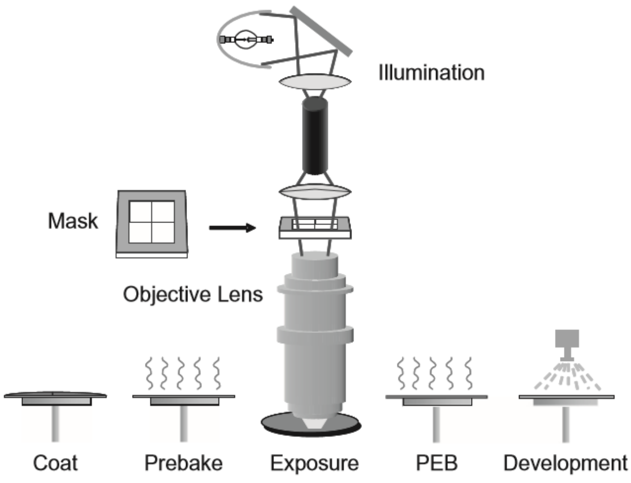

Fig.3 lithographic process steps

Selective doping of various regions of silicon allows the conductivity of the silicon to be changed with the application of voltage. By creating structures of these various components, millions (or even billions) of transistors can be built and wired together to form the complex circuitry of a modern microelectronic device.

Fundamental to all of these processes is lithography, i.e. the formation of three-dimensional (3D) relief images on the substrate for subsequent transfer of the pattern into the substrate. For the introduction of IC fabrication please see the references [2] for detail.

2.2 Organizing evolving cases

We use Fig.4 to analyse evolving cases and organize real cases along different development threads. (e.g. Architecture complexity, static and dynamic, decrease of wavelength etc.)

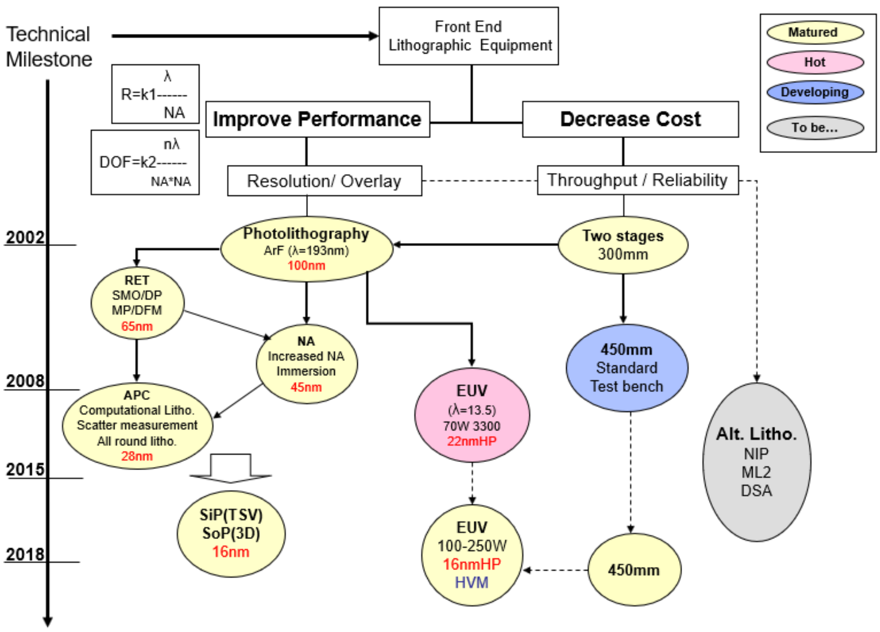

Fig.4 Innovation in lithographic industry

We introduced a new way of analysing contradictions in problem by choosing multiple advantage and disadvantage parameters to illustrate a statistical distribution for inventive principles. System engineer in SMEE have been using it as a tool for looking for inventive solution in the TRIZ matrix. Also TRIZ method has seen continuous development, for example, TRIZ matrix was updated and improved by D. L. Mann (ref. [6] and [7]) in 2003. The source data is based on Mann's TRIZ matrix 2003. Fig.5 shows the difference between them.

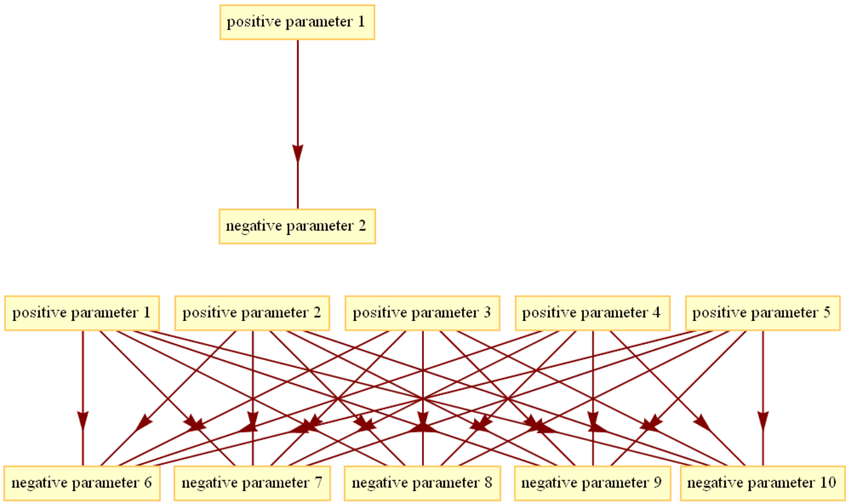

Fig.5 One to One vs. Multi to Multi parameters

Contact and proximity lithography are the simplest methods of exposing a photo resist through a master pattern called a mask and it is the starting node of lithographic evolution tree (See Fig.2). Contact lithography offers reasonably high resolution (down to about one wavelength of radiation), but practical problems such as mask damage (formation of mask defects) and resulting low yield make this process unusable in most production environments.

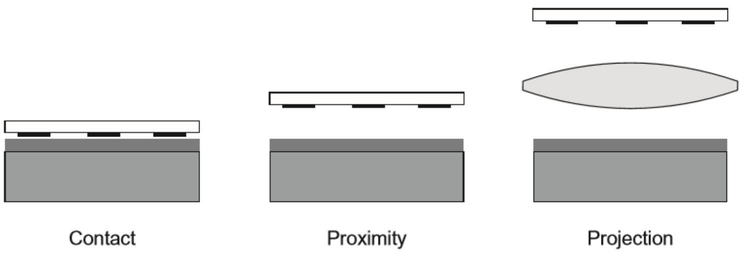

Fig.6. Three main development stages of lithography

Proximity printing reduces mask damage by keeping the mask a set distance above the wafer (e.g. 20 micron). Unfortunately, the resolution limit is increased significantly. For a mask wafer gap of g and an exposure wavelength of λ, the limit of resolution is $\sim g\,\lambda$.

Because of the high defect densities of contact printing and the poor resolution of proximity printing, by far the most common method of exposure is projection printing. Projection lithography derives its name from the fact that an image of the mask is projected onto the wafer using a lens.

Projection lithography became viable in the mid-1970s with the advent of computer-aided lens design. Semiconductor manufacturing has evolved from using contact printing (in the early 1960s) to projection printing (from the mid-1970s to today). Improved optical materials and manufacturing methods allowed the production of lens elements of sufficient quality to meet the requirements of semiconductor industry.

	First Stepper(1978)	Immersion Scanner(2006)
Wavelength	436nm	193nm
Numerical Aperture	0.28	1.2
Field Size	10x10mm	26x33mm
Reduction Ratio	10	4
Wafer Size	4"(100mm)	300mm
Throughput	20 wph(0.44 cm^2/s)	120 wph(24 cm^2/s)

Fig.7 The change in projection tool specifications over time

2.3 Using major evolving steps as innovation cases

There are two major classes of projection lithography tools – scanning and step-and repeat systems. Full-wafer scanners replaced proximity printing by the mid-70s for device geometries below 4 to 5 micron. By the early 1980s, steppers began to dominate as device designs pushed to 2 micron and below, exposing a whole wafer in many steps. Steppers have continued to dominate lithographic patterning throughout the 1990s as minimum feature sizes reached the 250-nm levels.

However, by the early 1990s a hybrid step-and-scan approach was introduced. The step-and-scan approach uses a fraction of a normal stepper field (for example, 26 × 8 mm), then scans this field in one direction to expose the entire 4× reduction mask (see Fig.2). The wafer is then stepped to a new location and the scan is repeated. The smaller imaging field simplifies the design and manufacturing of the lens, but at the expense of a more complicated reticle and wafer stage. Step-and-scan technology is the technology of choice today for below 250-nm manufacturing.

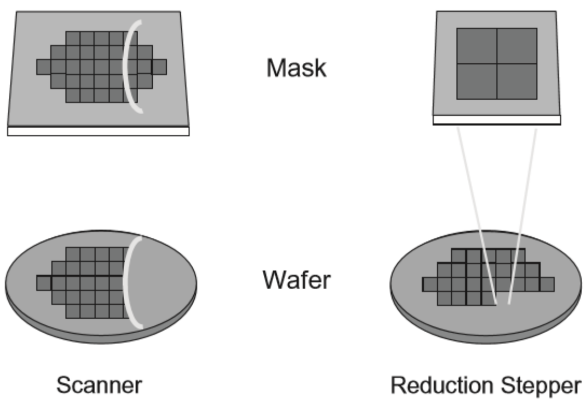

Fig. 8. Scanners and steppers use different techniques for exposing a large wafer with a small image field [2]

What we do is organizing innovative cases stated above according to evolution history of lithography as follows:

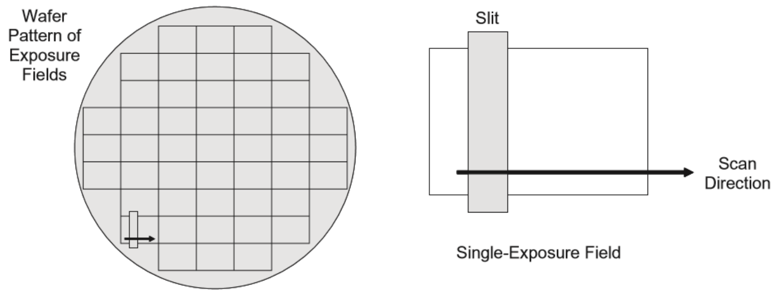

Fig. 9 In step-and-scan imaging, the field is exposed by scanning a slit that is about 25 × 8 mm across the exposure field[2]

More specifically in lithography industry, advanced wafer stage or reticle stage are key subsystems to improve productivity. However to design and development an efficiency stage has more factor need to consider, Fig.10 and Fig.11 show the stage requirement conflicting triangle and it is actually three advantage factors against three disadvantage factors.

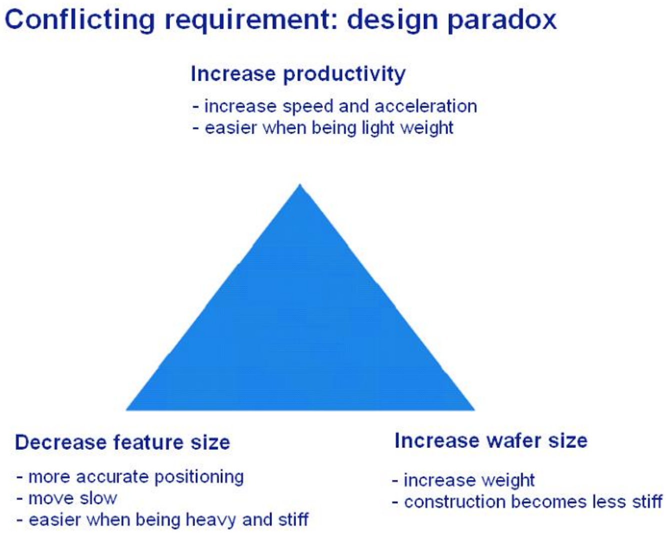

Fig. 10 Contradictions of advanced stage development

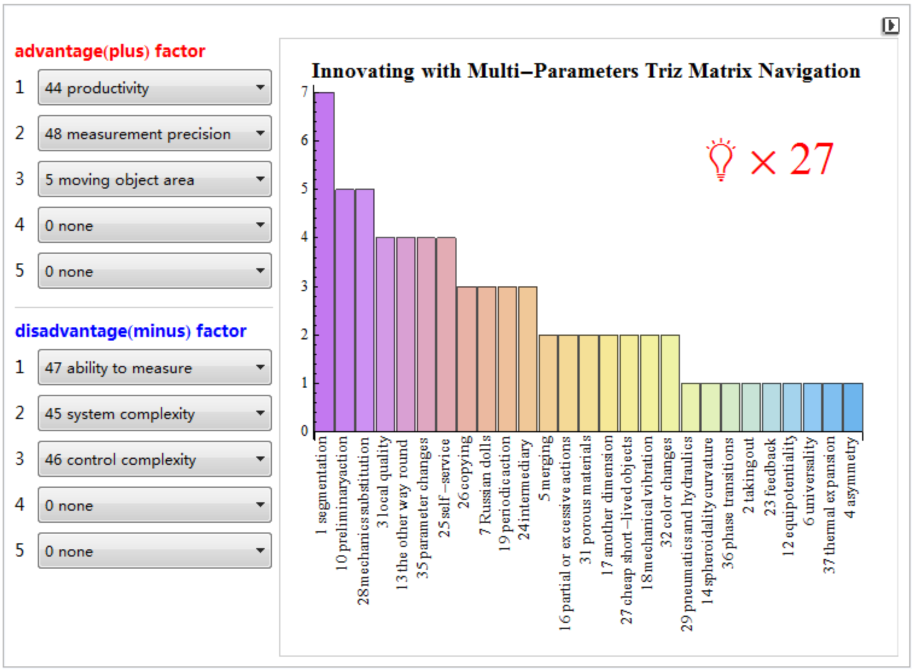

Fig.11 Case study (three parameters to three parameters)

2.4 Tool-Object co-evolution

The concept of co-evolution is originally from biology which have many explanations like animals and plants evolving in response to one another, specifically it can describe competitive or cooperative relationship between two living species, so they can all evolving to survive. In this technical context, we use these analogies of Tool-Object pair and show the interesting evolving phenomena happening in lithographic evolution history, see Fig.12 and Fig13. bellow. There are many innovation cases that show this co-evolution in dynamical trend of lithographic subsystem development.

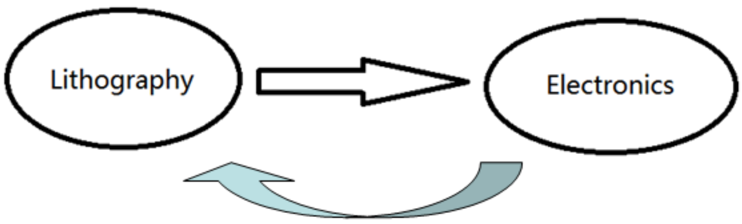

Fig.12 Tool- object pair analogy

For example DMD (Digital Micromirror Device) is a type of MEMS (Micro-Electro-Mechanical System) which can only be made using lithography technology and then could be used to replace mask. When used in a lithography system, a DMD will dynamically change pattern according to customer needs. These kinds of MEMS are also used in dynamic generation pattern to illuminate mask to enlarge processing windows such as increase depth of focus etc.

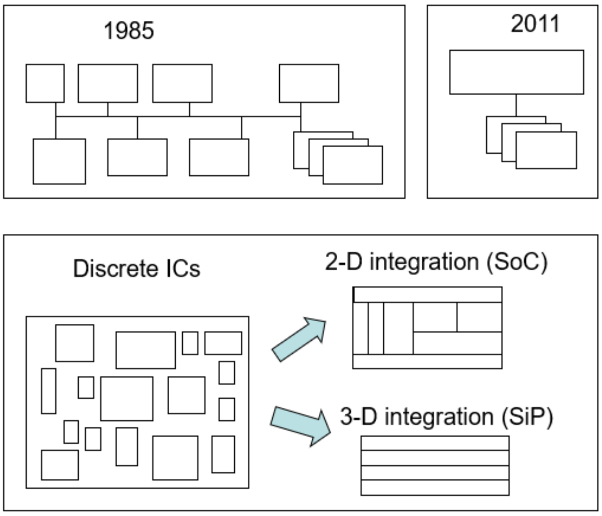

Fig.1 Electronics evolution trend

3. Result and Discussions

We have collected many examples of technology changes in lithographic history and organized it according to an evolution tree. In every innovation case, we analyse the problem from emerging contradiction, idealistic and multi-window aspects. We also expand these processes to electronics industry and organize it into tool-object co-evolution knowledge base.

System engineers in SMEE are now actively participating in building and discussing on how to further improve these examples. Through these activities, they gradually learn how to solve the problem in project context and gain confidence to overcome the difficulty they meet. They also have given a clever algorism and introduce a new way of thinking by choosing multiple advantage and disadvantage parameters to illustrate a statistical distribution for inventive principles, instead of looking up as single parameter to single parameter on TRIZ Matrix.

Innovative cases studies are followed to illustrate the necessary and convenience to deploy multiple factors, which fit real modern industry requirement or specification. The software is developed under Wolfram Mathematica, System engineers may move there mouse over each bar to see the tool tips of 40 inventive principles and can use it as a tool for looking for an innovative solution in the TRIZ matrix.

4. Conclusions

We organize many types of cases into an evolving tree between lithography and electronics co-evolution to show that innovation comes from overcoming contradiction and towards an ideal solutions. We actively locate the contradictions in existing products and use them as a gate to make SMEE competitive in global market.

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MASTER STUDENTS LEARNING TRIZ AT THE UNIVERSITY: PAST EXPERIENCES, FUTURE PLANS, AND BEST PRACTICES

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Abstract

Creating an efficient learning environment for TRIZ at a university is far from trivial. Although the TRIZ-tools for solving problems can appear simple at a glance, applying them to real world problems by beginners is not. In this paper we share our experiences teaching and developing a university course in TRIZ for Master students with different Engineering backgrounds. The syllabus of the course is presented, student results and feedback are analyzed, and plans for future course development are discussed.

Keywords: TRIZ Education, University, Master students, Learning environment

1. Introduction

1.1. Very nice and interesting, thank you, but what have I actually learnt?

Problem solving is central to life. Acquiring practical problem solving skills is therefore essential – in particular in the context of engineering student education. Engineering students face and solve problems continuously throughout their education, but the problem solving process itself is seldom the focus of attention. A course devoted to problem solving is an important opportunity for students to orient themselves of alternative ways of solving problems and to challenge their own approaches.

The theory of inventive problem solving (TRIZ) is, in this respect, a suitable topic. It is a systematic approach to problem solving that provokes the user to think creatively about a problem [1]. TRIZ offers a set of objective rules, or models, for the user to map the specific problem on more general problems, and from these, abstract conceptual solutions that can be turned into specific solutions to the problem at hand [2,3]. With a balanced attention to both problem definition and problem solving – and with an ideal final outcome in mind – TRIZ holds the promise of guiding the user into a non-biased state-of-mind and through a process that leads to solutions that are unique, simple and elegant [4]. Given these promises, TRIZ is a subject that should appeal to engineering students – and initially it does.

A challenge we have identified, however, offering a university course on the subject to Master students, is to leave the students with a confidence in TRIZ as an immediately applicable, practical resource for the future – not only a theoretical curiosity. This challenge is well-known and has been linked to pedagogics, often with the aim of promoting new ways of teaching TRIZ; "old-way" training, for example, have been argued to lead to "fuzzy understanding" and "insurmountable barriers" to practical application [5]. The "instructor effect" – the dependence on the learning outcome on highly experienced and skilled instructors – is another problem that has been put forward [6]. The way forward, we believe, is not so much to identify the "right teaching method" or hire the most skilled TRIZ instructor, but to develop a flexible and dynamical learning environment that serves the education goals.

TRIZ education at universities is not a new phenomenon, but has in recent years become more visible in what has been dubbed a "world of consultants" [7]. An excellent introduction to the challenges of TRIZ education and the important role of universities is provided by Wits *et al.* in their documentation of a comprehensive (140h) and intense TRIZ course for Master students at the University of Twente [8]. Overall, the growing substance of literature on TRIZ projects and education carried out at universities helps to make the pros and cons, and the educational aspects of TRIZ, more transparent. Previous studies address, for example, the impact of TRIZ on innovative thinking problem solving skills of university students [9–16] and the dependence of the learning outcomes on the specific learning environment. The latter include the effect of format (lectures, tutorials, projects) [7], content (academic, best practice, or real-life problems) [17], the use of software or other pedagogical tools [6,18,19], and the importance of student-student and student-teacher interactions [7].

In this work we present and discuss the learning environment for TRIZ, with respect to the second topic, in the specific environment of our university course. What was our starting point, what have we learnt during the two semesters that we have been in charge of the course, how have we modified the course accordingly, and what are our plans for the future? Our aim is not to provide "*the*" solution, but to contribute to the discussion of how to create efficient learning environments for TRIZ at the university within a given context. The essence is very well captured by Cavallucci et al. [6] to *"bring engineering students to a level of TRIZ understanding that will enable them to use it in their future industrial experiences"* or elsewhere.

2. Course background

2.1. Why and how is a Physics department offering a TRIZ-course?

The TRIZ course *"TIF185 Creative problem solving in Engineering"* comprises 7.5 ECTS (European Credit Transfer and Accumulation System) merit points, where one year of full-time studies is equivalent to 60 ECTS. Our course corresponds to 5 weeks of full-time studies, or approximately 200 hours, spread out over a formal study period that extends from the start of November to mid-January. This is a rather ambitious scope, since most TRIZ training worldwide is limited to 20 hours or less according to a survey by the European TRIZ association [20]. However, as detailed further down, a majority of the work by the students occurs out-of-class.

The course attracts *ca.* 15 Master students every year. Characteristic is that we have a mix of students from different countries and from different programs and relatively few teacher-lead learning activities. This is partly due to budget restrictions, but also based on the idea that a final project should make up a considerable part of the course.

The course was first introduced in 2008 under the name *"Special topics in applied physics"*. The intention of the course was to offer students a new topic each year, not covered by the standard curriculum, but TRIZ remained the subject of the course and the name was changed. The authors of this paper took over responsibility for the course in 2014. We each have roughly

80 hours of formal TRIZ training from attending various workshops offered by consultants in the field; *Oxford creativity*, *The International TRIZ Association (MATRIZ)*, and *The TRIZ group*. As our training is relatively modest, we are by now means TRIZ experts, which adds to the challenges of designing and running the present course.

With the course we inherited a learning environment essentially structured around a set of *lectures/workshops*, which introduce the basics of TRIZ, an extended *team-based project work*, and *a written final exam*. The project constitutes approximately 60% of the total course work, reflected in the grading of the students' work (60% Project, 40% Exam). As mentioned, the majority of the work by the students occurs out-of-class, in the form of team-based projects.

Our first year (2014), we decided to keep the changes to a minimum, including the course book *Innovation on Demand* [3], but to carefully monitor the course work for future developments. The in-class activities of the course 2014 consisted of approximately 8 hours of lectures and 12 hours of practical exercises (Table 1).

In preparation for the class of 2015 we made a number of changes to improve the learning environment based on student feedback and our own experiences from 2014. The hours in-class remained effectively unchanged (not counting a few additional hours for mini-exams, project information, and supervision), but were now formally distributed as 4 hours of lectures and 16 hours of Workshops (Table 1).

Table 1

Overview of in-class activities during 2014 and 2015

2014		**2015**	
W	**Activities**	**W**	**Activities**
1	Lecture 1 (2h) *Basic Theory and Tools*	1	Lecture 1 (4h) *Basic Theory and Tools*
1	Lecture 2 (2h) *SU-Field*	1	Workshop 1 (4h) *Basic Tools*
1	Exercise 1 (4h) *Basic tools*	2	Workshop 2 (4h) *SU-Fields, Creax software*
2	Lecture 3 (2h) *ARIZ*	2	Mini exam 1 (2h) *Covering WS1 and WS2*
2	Exercise 2 (4h) *Creax software*	2	Project information (1h) *Project initiation*
3	Lecture 4 (2h) *ARIZ, Project initiation*	3	Workshop 3 (4h) *ARIZ*
3	Exercise 3 (4h) *ARIZ*	3	Workshop 4 (4h) *Trends of evolution, S-curves*
		4	Mini exam 2 (2h) *Covering WS2 and WS3*
		6	Mid-project presentations (2h)
7	Project presentations (2h)	7	Project presentations (2h)
	Break for Christmas		*Break for Christmas*
10	Final exam (4h)	10	Final exam (4h)
	Total in-class activities = 26 h		**Total in-class activities = 33 h**

W = Course week. Number of in-class hours (h): 1h = 45 minute activity + 15 min break. WS = Workshop. Basic theory and tools: 9-Windows, Function Analysis, Contradictions, Ideality.

3. Course development

In this section we review the main elements of the 2014 syllabus and the changes made for 2015. We also present some trends observed in a general course survey that students complete for every course. The limited scope of this paper excludes an exhaustive presentation of details; instead, the focus is the general lines of development.

3.1. From Lectures and Exercises to Workshops

The most important observation or realization in the 2014 edition of the course was that too much time was concerned with teaching and not with learning. Our impression was that students were left too passive, in particular: *i)* listening to lectures on TRIZ, although perfectly adequate, are not efficient when it comes to real problem solving. It is our opinion that lectures on TRIZ often provide a false sensation of understanding. *ii)* The lack of formative assessment during the course allowed the students to stay too long in the "false" sensation that they understood the different methods from the lectures. However, *the devil is in the details* and if the methods are not really applied to real problems by the students themselves, not much is really learned.

For the exercises, we realized that: *i)* Exercise 1 contained too much substance, it was not necessary to have a full exercise on the Creax software, and *ii)* the present course would benefit from additional literature – complementary to the main literature of the course.

The number of hours for lectures and exercises, relative the total number of hours students are expected to invest, is very small in our course in comparison with other TRIZ courses [6,7,21], but the distribution of hours between lectures and practical sessions is similar, and the reference courses are not all exclusively limited to TRIZ. The number of in-class hours in our course, however, is difficult to increase based on budget restrictions due to the relatively few students enrolled in the course. Modifications are therefore focused towards an optimal use of hours.

In 2015 we reduced the number of formal lectures to one 4-hour introduction lecture, where the general concepts and basic tools of TRIZ (9-windows, Functional Analysis, The Contradiction matrix, and the Ideality principle) were introduced. The content of the remaining lectures and the practical exercises of 2014 were integrated into workshops more focused on applied problem solving. By reducing the time spent on the software we were able to devote almost a full workshop to SU-field analysis.

3.2. Clarifying Project Instructions and Expectations

The challenges connected to the project work are to prepare the students adequately for the task, to find problems at a suitable level, and provide sufficient support during the problem solving process.

Students were assigned to project groups of 3-4 with a good mix of educational and cultural background. Despite some initial adaptation and rare problems with the group dynamics, the students appreciated the opportunity to work in the mixed groups. A new development for 2014 was to let the students tackle real problems posted by companies at an innovation challenge site [22]. Each group was allowed to select one out of a pool of five preselected problems. The task was threefold: *1)* Analyze the problem using TRIZ principles, *2*) suggest solutions to relevant system conflicts, and *3)* predict the evolution of the technology.

The realistic problems gave an edge to the problem solving process, but were in some cases overwhelming and lead to outcomes of varying quality. Students were encouraged not to jump to an obvious solution, but we still experienced that some groups "locked into" a given solution early and were paying too careful attention to the opinion of domain authorities within the group. The students themselves expressed that information about the project came too late – not until after the final lecture – and were concerned about the structure of the project being unclear.

The project work was carried out entirely out-of-class with the exception of a 30 min supervision meeting with each of the five groups halfway through the projects. The meetings were setup to ensure progress and provide a feedback opportunity. It was not immediately clear if these meetings had a positive impact on the project work.

List of project topics 2014

Transformational Packaging Solutions for Temperature Sensitive Products
Reducing Galactic Cosmic Rays to Enable Long Duration Deep Space Human Exploration
The Next In-Car User Experience

List of project topics 2015

Anti/de-icing Solutions for Distribution Networks
High-speed, Large Scale Controlled Separation of Water and Solids
Identification Coding on Medical Instruments
New Ways to Kill/Trap/Repel Insect Pests in the House

In 2015, the students were divided into groups and informed about the project already after the second workshop. Expectations were communicated more clearly by providing a template, which structured the project into five parts: *1)* Problem statement, *2)* Analysis of conflicts, *3)* Analysis of resources, *4)* Development of conceptual solutions and *5)* Evolution of technology. Each part was supported by additional information about expectations and suggestions of useful TRIZ tools.

The early formation of project groups and template had several positive impacts; *i)* the group members were required to work together in the remaining two workshops to get to know each other, *ii)* the groups could start the planning of the projects earlier, and *iii)* the project outcomes (reports and presentations) were more uniform and of better quality. The feedback opportunity halfway through the projects was in 2015 complemented by a full in-class feedback session, where each group was able to receive and give their peers feedback on the project standings based on short 10 min presentations.

3.3. From a Final Exam to Formative Assessments

In 2014, students were graded based on the project work (60%) and an open-book Exam at the very end of the course (40%). All 15 students completed the course with a pass and the average grade (on a scale of 3-5) was 3.9. The average student score on the project was 13.2 (out of 20) and for the Exam 13.9 (out of 18).

For the class of 2015 we introduced two voluntary written mini-exams, as formative assessments at a much earlier stage, in addition to the final exam and project evaluation. All students were encouraged to take the mini-exams and were awarded a bonus point for a pass, which was added to the score of the final exam. Each mini-exam provided the students an opportunity to demonstrate proper use of the TRIZ tools introduced so far. We can see that this improved the learning in two ways. Firstly, the students were forced to do some serious studying to prepare for the mini-exams and secondly we received some important feedback on what the students found difficult. The mini-exams were organized as two-hour activities, where the first hour was assigned for the exam and the second hour was used for a collective reflective analysis of the exam.

The 14 students of the class of 2015 completed the course with an average grade of 4.2 out of 5. The improvement in results was due to improved scores on the final exam 16.9 out of 20 (including two bonus points). The average project results (13.5 out of 20), however, were similar to the previous year. The scoring is subjective and to some extent difficult to judge, but our overall impression is that the students benefited from the formative assessment and that project outcomes were improved. Still, the project outcomes, *i.e.* the ability of the students to apply TRIZ to solve realistic problems, could (in our opinion) improve much further with the appropriate measures.

3.4. Student Surveys Direct Future Development

A summary of the course evaluations from 2014 and 2015 is shown in Table 2. The survey was completed by 7 (47%) of the students in 2014 and 12 (86%)! of the students in 2015. The difference in answer frequency can to some extent be explained by the fact that we in 2014, at the end of the in-class activities and in addition to this formalized University course survey, conducted a student survey of our own (unfortunately this was not done 2015). This could have decreased some student's motivation to answer a second survey. Although one should not over-interpret the data, the results are both encouraging and surprising at the same time. It is encouraging to see the consistent improvement in the rating of the individual statements, while at the same time surprising that the total grade of the course has not changed.

Our analysis is that despite the improved quality of the various elements of the course the students were still not completely convinced of the use of the course and whether they had actually learned something useful or not. This is indeed also our experience from different workshops by professional companies. Insufficient feedback on the project work is one of the things that need to be improved according to comments by individual students in connection with the survey of 2015. In addition, we believe that students are not yet given adequate opportunity to experience that they can successfully apply the TRIZ tools to real problems.

Table 2

Student survey results from 2014 and 2015

Survey statements (rating 0-5, where 5 = total agreement)	**2014**	**2015**
The course structure is appropriate in order to reach the learning outcomes	3.43	4.42
The teaching worked well	4.14	4.42
The course literature supported the learning	3.71	4.50
The assessment tested whether I had reached the learning outcomes	4.00	4.08
The course administration worked well	4.29	4.67
Sum	**19.57**	**22.09**
Overall satisfaction with the course	**3.86**	**3.83**

Selected student responses:

"Feedback on the work could be better. After the first presentation almost no feedback was given."

"A meeting with the teachers (is required) earlier in the process for the project work. If things have to be changed it is quite a rush otherwise."

"Will what I've learned from this course really help me in the future? Is this topic really that

important? I'm not sure yet, but maybe."

4. Conclusions and Future Development

Course development is like peeling an onion. Once one level of problems has been addressed a new level is exposed. Based on the previous discussion, we have several lines of developments in pipeline for the course.

A general question is how we should optimize the student learning and make better use of both the few in-class activities and more abundant out-of-class activities (*ca.* 160 hours formally distributed over 8 weeks). A particularly useful pedagogical method to address this question is the principle of Constructive Alignment [23] where, in short, a set of intended learning outcomes (ILO), and the methods to assess these, are defined, after which a suitable ensemble of teaching and learning activities are selected to bridge the ILO with the assessments. Such a recalibration of the course has yet to be performed.

On a more detailed level, the next step is to improve the students' skill to independently apply TRIZ to solve real problems. We have several ideas how to facilitate this; the first idea is to compile a considerable set of pedagogical exercises, many with solutions, which are possible to solve without domain knowledge and without the guidance of a teacher. This provides a routine for how to apply the methods on a variety of problems and, not the least, confidence in the methods. Different types of problems (academic, best practice, and real-world problems) serve different purpose of illustrating methods, motivating students *etc.*, which should be taken into account [17]. As suggested elsewhere, a centralized (web-based and open) database with pedagogical TRIZ problems would be an important asset [5]. However, the willingness to make use of, but not contribute to, such centralized information appears to represent a paradox [20].

The second idea is to improve the efficiency of learning before and after the workshops by helping the students prepare in advance, both in terms of skill and mind-set. A list of recommended reading is not a sufficient complement to in-class activities. Suitable pre- and post-workshop tasks should encourage active engagement, individual reflections, and lead to a deeper understanding of the material. Such improvements would also allow the workshops to focus more on hands-on problem solving and cooperative learning/reflections [7], in place of establishing the framework. The idea is closely connected to, and can take advantage of, the principle of constructive alignment and the concept of a *Flipped Classroom* [24].

The third idea relates to the development of the project part of the course, but it is not obvious how to proceed. One possibility is to integrate the projects more closely with the workshops, applying the tools directly within the project [16], but drawbacks are that the students have not yet reached a level where they are comfortable with the tools and are not allowed to critically reflect over the appropriate tools for their projects. To practice TRIZ on authentic problems, without knowing the outcome beforehand, is arguably an essential part of exploring and learning the different tools, but also very challenging. The uniqueness of the problem requires a more experienced user and makes it more difficult to turn to the teacher or literature for help. For both the teacher and student it can be an intimidating experience; the teacher has little control over the outcome and shares a fear of failure with the student. What if? The different and varying activities of the course require the teacher to take different, appropriate roles, depending on the activity – in particular to be prepared to discover authentic problems together with the students as experienced colleagues [7], which takes some practice.

An alternative to a single, large project is to replace it with one or several smaller individual and one intermediate sized team project. The smaller projects could be valuable out-of-class activities to prepare the students for the larger projects and allow for mistakes, *i.e.* not to put all eggs in one basket. By involving the student in the choice of topic of the small project, these could offer more personalized and varied learning opportunities. Small projects could, for example, involve the analysis of patents [25] or trends for systems of particular interest for the student. The project outcome could be appropriate for pair-wise peer-review among the students to facilitate cooperative learning.

To conclude, it is obvious for us, when researching for and writing this paper, that we are in part rediscovering well-known problems within the community that could partly have been foreseen by an earlier awareness and improved connectivity with the field. However, there is clearly also a clear need for further exchange and dialogue about appropriate activities and environments for learning TRIZ at universities, to which we hope to contribute with this and future work.

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OPERATION PRINCIPLE DEFINITION THROUGH PATENT PRACTICES

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Abstract

While the definition of "principle of operation" is a commonly used term in many engineering and non-engineering fields, for TRIZ domain it holds a much more important significance. A number of TRIZ tools and methods are based on the notion of difference in principle of operation (for example, S-Curve analysis) and require clear and definite criteria for distinguishing different principle of operation.

The article focuses on the research of the patent lawsuit materials for identifying major criteria for establishing commonality or difference in principle of operation of engineering systems

Keywords: TRIZ, principle of operation, doctrine of equivalents, infringement.

1. Operation Principle Definition

An accurate definition of "principle of operation" or "action principal" is a key issue in many TRIZ tools and procedures. It is widely used in Innovation Benchmarking, MPV discovery, S-Curve Analysis, Long Term Forecasting and others. Search in encyclopedias, dictionaries and other generic sources has not led to any definition or a set of criteria acceptable for TRIZ – all the found definitions were generic because the detailed criteria were not needed in those fields. For example, the most common definition of "principle of operation" that can be found in literature is a principle according to which the system operates.

The method that was offered for identifying the most accurate definition of the action principle was based on a TRIZ tool called Function-Oriented Search (FOS). Function-Oriented Search is a problem-solving tool that uses functional criteria to help identify existing technologies in leading areas of science and engineering. The focus of Function-Oriented Search is on relevant industries or knowledge domains that face functionally similar challenges to the client's system.

Typically, the most rewarding domains to explore are those industries where the function is absolutely critical to the survival of the industry. In our case it necessary to look for areas where an accurate definition of the action principle would be of primary importance for decision-making – financial, legal, criminal, etc.

The application of the FOS approach lead to the domain of the US Patent Law, specifically to the part of it that deals with the Doctrine of Equivalents. The Doctrine of Equivalents is a legal rule in many (but not all) of the world's patent systems that allows a court to hold a party liable for patent infringement even though the infringing device or process does not fall within the literal scope of a patent claim, but nevertheless is equivalent to the claimed invention. U.S. judge Learned Hand has described its purpose as being "to temper unsparing logic and prevent an infringer from stealing the benefit of the invention".

In the United States, the Doctrine of Equivalents analysis is applied to individual claim limitations, not to the invention as a whole. The legal test, articulated in Warner-Jenkinson Co. v. Hilton Davis Chem. Co. (1997), is whether the difference between the feature in the accused device and the limitation literally recited in the patent claim is "insubstantial."

One way of determining whether a difference is "insubstantial" or not is called the "triple identity" test. Under the triple-identity test, the difference between the feature in the accused device and the limitation literally recited in the patent claim may be found to be "insubstantial" if the feature in the accused device:

1. Performs substantially the same function
2. Is based on the substantially the same operation principle
3. To yield substantially the same result.

As you can see the “triple identity test” requires a very precise identification of the principal of operation. The “triple identity test” may be critical for the court decision on infringement. That is why the materials of patent lawsuits around applicability of the Doctrine of Equivalents may contain pretty definite criteria for judging if engineering solution belongs to the same or different operation principles, the “operation principle” being one of the major criteria for establishing the fact of infringement.

The analysis of the materials of 14 lawsuits on patent infringement allowed to clarify the process of determining the action principle or “principle of operation”. The procedure can be summarized as the following algorithm:

1. The patent judge identifies patent claims for comparison and splits them into components that the claim contain.

2. The judge performs so called “element-by-element comparison”, that is checking correspondence of every component of the patent in question with the components of the infringing solution. The “element-by-element comparison” is the first infringement check. If there is no correspondence of the components, the infringement case may be dismissed. Because of this fact the competitive patent circumvention strategy by trimming is much more preferable than the substitution strategy – trimming eliminates one of the components of the competitive patent so the fact of infringement is much more difficult to prove.

3. In case of correspondence of the elements the judge performs the second check to applying the “triple identity check” to every couple of the compared components by:

    a) identifying their functions

    b) identifying physical/chemical method of performing the function that is a method of changing a specific function parameter.

4. The infringement is established in case of similarity of the physical/chemical way of performing the functions.

As a hypothetical example, let us consider a well-known case of argon blow- through process in steel making. To prepare steel with special properties argon must be blown through the steel melted bath. Argon stirs metal in the ladle intensively and the metal temperature decreases via heat losses through the walls and the bottom of the ladle. The intensity of the purification reaction decreases. A patented by ThyssenKrupp solution to this problem includes equipping the ladle with a jacket wall and evacuating air between the walls with a compressor.

Application of the patent circumvention strategy by trimming allowed to trim the compressor and to delegate its function to the argon pipe by designing it in the shape of a Venturi tube (solution 1).

Another solution (solution 2) would be filling part of the space between the walls with a powder that absorbs air at heating and releases it at cooling. In this case the compressor is substituted with the air-absorbing powder.

In case of a lawsuit of ThyssenKrupp the patent judge would have probably handled the case the following way.

Solution 1. Trimming of the compressor and delegating its function to the argon pipe would lead to the fact that the element-by-element comparison showed the absence of correspondence of components and the case would have been closed. No infringement would have been established.

Solution 2. The element-by-element comparison would have established the fact that instead of the compressor in the ThyssenKrupp solution there is the air-absorbing/releasing powder and the judge would have ordered the second round of the expertise – “the triple identity check”. The functions that the compressor and the powder perform are same – they remove air from the free space between the walls of the ladle. However, what are the physical methods or removing the air? In Solution 1 it is mechanical compression, in Solution 2 it is chemical binding. Those are quite different operation principles so the components the compressor and the powder would not be recognized as equivalents and no infringement would be established.

2. Conclusions

Summarizing the research it is possible to say that the parent practice defines the action principle (principle of operation) at a method to perform a specific function (to change/maintain a parameter) of corresponding components in engineering systems.

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ORGANIZATION INNOVATION EMPLOYING TRIZ UNDER QUALITY INNOVATION MANAGEMENT SYSTEM FRAMEWORK

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Abstract

Organization innovation has five main dimensions including Operational, System, Process, Product and Service innovation (Chin & Wong, 2004). Since most of organization had employed ISO 9001 Quality Management System, we would like to start the organization innovation based on QMS foundation. Moreover, the new Technical Specification 'Innovation management – Part 1: Innovation management system' (CEN/TS 16555-1:2013) is issued by Technical Committee (CEN/TC 389) of European Committee for Standard in 2013. It was found a system approach of innovation through the integration of QMS and Innovation Management System (InnoMS) to be synergized. Moreover, system needs some tools for implementation. The Theory of Inventive Problem Solving (TRIZ) is a creative thinking tool for quality professionals selecting innovative solutions and solves different physical and technical contradictions.

In this paper, systematic framework of Quality Innovation Management System (QInnoMS) will be introduced. Finally, a case study of systematic implementation of TRIZ approach under the QInnoMS framework will be discussed.

Keywords: ISO 9001:2015, CEN/TS 16555-1, Quality Innovation Management System, QInnoMS, TRIZ

1. Introduction

Quality is the prerequisite of innovation. Innovation makes sense for business sustainability only if products are safe and reliable. As product life cycles condense and substitutive product offerings expand, product innovation becomes increasingly outstanding for establishing sustainable competitive advantage. Thus, innovation is an essential element for sustaining competitiveness (Krause, 2004), and it masters the trend and the future for the organization in this rapid changing business environment (Daellenbach, *et al.*, 1999). Chin & Wong (2005) attempted to develop a comprehensive self-evaluation frame work for organizational innovation. However, they hadn't considered the recently new ISO 9001 standard (in version 2015) of Quality Management System (QMS) and CEN/TS 16555-1:2013 Innovation Management System (InnoMS). Therefore, the integration of QMS and InnoMS is proposed to form Quality and Innovation Management System (QInnoMS) framework for systematic organization innovation.

The Theory of Inventive Problem Solving (TRIZ) is a handy tool for realizing that contradictions can be methodically resolved through the application of innovative solutions. There were three key concepts which the theory is built that (a) the ideal design is a goal, (b) contradictions help solve problems, and (c) the innovative process can be structured systematically. I had attended MATRIZ Certification Level 1 Training on 19, 20, 26 & 27 April 2013 and MATRIZ Level 2 Training on 18, 19, 25 & 26 May 2015 which organized by Institute of Systematic Innovation, Hong Kong (ISIHK). In this MATRIZ Level 1 course, TRIZ techniques are included "The Nine Windows", "Ideality and Ideal Final Result", "Function Analysis", "Cause Effect Chain Analysis", "Trimming", "Technical and Physical Contradiction" and "40 Inventive Principles" which had employed for Technology Support Centre of Hong Kong Science and Technology as preliminary case study.

2. Organizational Innovation

Organizational innovation is that they adopt an idea or behaviour which is new or novel to the organization. Innovation inspires changes in the way how organization or part of the organization operates and delivers their product or service (Hage, 1999; Nystrom, et al., 2002). Organizational innovation can be divided into five main categories which also stated in the CEN/TS 16555-1:2013 Innovation Management System (InnoMS) under Innovation vision and strategy development. The innovation strategy should define what kinds of innovation should be focused on such as system/process, operational, service and product. They were:

- System/Process innovation addresses introduction of new elements which involve coordination of a group of members such as performance appraisal, incentive systems, resource allocation, etc. In 2002, I established a professional consultancy company to service industry. Since it is a SOHO (small office, home office) company, the resource is very limited. Based on Quality Management Principles implementation and lean system on one man operation, the company was certified by HKQAA on July 2002 (within four month). It is valuable to introduce this approach to the knowledge-based alliance organization such as consultants' firm, doctors' clinic, lawyers / solicitors, accountants firm and certification bodies to foster TQM philosophy (Lai, Lotto K.H., 2003).
- Operational innovation changes or improves the way how organization does its business with their new methods, styles and equipment. Using my SOHO Company as example, many consultancy company audits are based on the checklist which design followed the ISO9001 clauses. In here, the audit checklist is based on 8 Quality Management Principle in which linked to Quality manual / ISO9001 clause was created (Lai, Lotto K.H., 2003).
- Service innovation addresses new service introduction to meet their internal or external client needs (Mohamed, 2002). There are many famous cases related to service innovation such as Dell, FedEx, 7 eleven, etc. Those companies aware customer special needs such as tailor-made computer, fast delivery of good and convenience buying good at night.
- Product innovation addresses end product alteration offered by the organization (Cooper, 1999). For automotive Industry, it had been invented in the late nineteen century. Safety belt, ABS (anti-lock braking system), and air bags are well-known three most important innovative products in the history of passenger cars (Lu, I.Y., et al., 2005)

3. ISO 9001:2015 Quality Management System (QMS)

The ISO 9001:2015 will respond to the latest trends and be compatible with other management systems such as ISO 14001. Moreover, Nigel Croft, Chair of the ISO subcommittee said "The new version is very strongly based on three basic core concepts: that process approach which was very successful in the 2008 version of the standard superimposed on that system of processes is the plan-do-check-act (PDCA) methodology, and a third core concept which is new in the 2015 version is risk based thinking, aiming at preventing undesirable outcomes."

There are several key changes in ISO 9001:2015 and described below:

- Adoption ISO Directives “Annex SL” – a high-level structure (HLS)
- Risk-based Thinking (Actions to address risks & opportunities)
- Fewer prescribed requirements
- Less emphasis on documents (Using Documented Information)
- Define the boundaries of the QMS (Context of the Organization in clause 4.1)
- Increase leadership requirements
- Organization knowledge

The revised Quality Principles are “Customer Focus”, “Leadership”, “Engagement of People”, “Process Approach”, “Improvement”, “Evidenced-Based Decision Making” and “Relationship Management”. The PDCA model of ISO 9001:2015 is shown in Fig. 1.

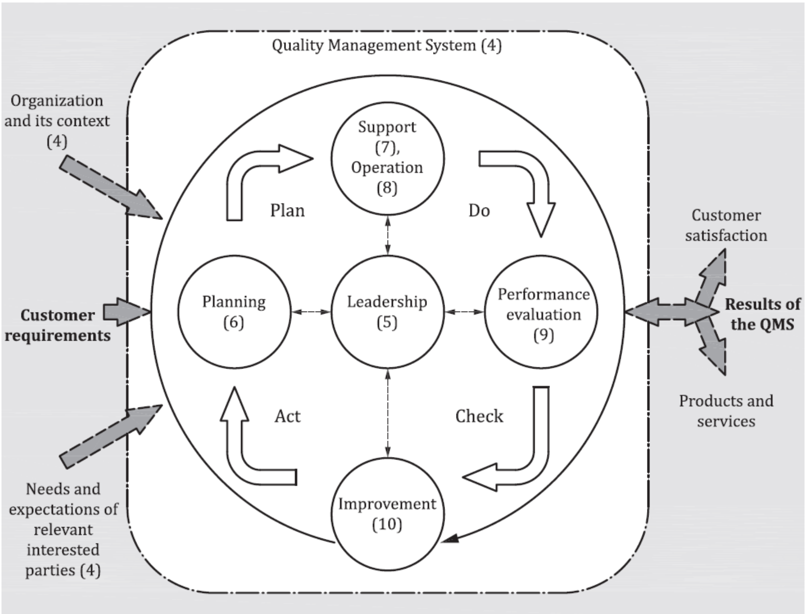

Fig. 1. ISO 9001:2015 PDCA model

4. CEN/TS 16555-1:2013 Innovation Management System (InnoMS)

The distinction between “Invention” and “Innovation” is that invention is the creation of a new idea or concept, and innovation is turning the new concept into commercial success or widespread use. Many companies recognized innovation is very important but they are considered to be highly innovative struggle to maintain a consistent and ongoing level of innovation. They need for systematic innovation. Then CEN/TC 389 for Innovation Management started to develop technical specification in November 2008 which initiated by Spain AENOR. The Technical Specification 'Innovation management – Part 1: Innovation management system' (CEN/TS 16555-1:2013) is the first in a series of seven technical specifications which pursue the following dimensions:

- Developing of an innovation strategy and vision
- Building an organization and culture to promote innovation
- Introducing a best-fit innovation process
- Using methods, techniques and tools to promote innovation
- Focusing and measuring the innovation result

This InnoMS standard aims of helping organization increase their innovation capability so that they can generate more value for their stakeholders. The model is also based on PDCA structure. InnoMS could be defined as set of interrelated or interacting elements of an organization to establish innovation policies and objectives as well as processes to achieve those objectives. The InnoMS model is showed in Fig. 2 which is based on CEN/TS 16555-1:2013 standard's figure1 plus figure 2. Innovation Management Process in the middle is called "Innovation Funnel" and its' aspect included framing and insight generation, idea management, develop of the innovation project, protection & exploitation of outcome and Market Introduction. The "Innovation Funnel" is the clause 8 in the CEN/TS 16555-1:2013 standard which corresponded to ISO 9001:2015 Clause 8 – Operation.

The CEN/TS 16555-1:2013 standard also adopted ISO Directives "Annex SL" – a high-level structure (HLS) except one more clause named "Clause 11 – Innovation Management Techniques". (See Table 1)

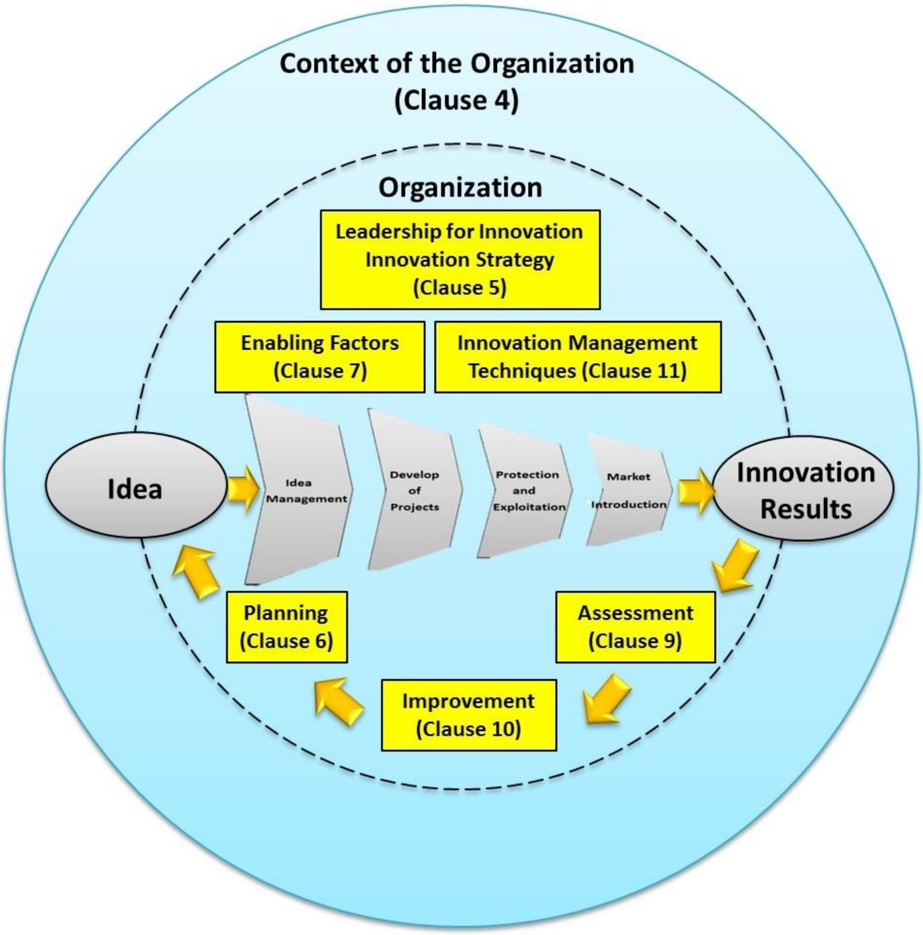

Fig. 2. Model of CEN/TS 16555-1 standard for innovation management system

5. Theory of Inventive Problem Solving - TRIZ

The Theory of Inventive Problem Solving (TRIZ) was developed in the former Soviet Union by Genrich S. Altshuller (1926-1998) who studied 200,000 patents and selected 40,000 patents as representing the most effective solutions from 1946 to 1948 (Terninko J. etal., 1998). He found that evolution of an engineering system is not a random event, but governed by certain patterns. Altshuller's key finding and developments included "Technical Contradictions (i.e. 40 Inventive Principles & 39 Engineering Parameters)", "Physical Contradictions (i.e. Four Separation Principles)", "Ideality" and "Algorithm of Inventive Problem Solving (ARIZ)", etc. The whole roadmap of MATRIZ Level 1, Level 2 & Level 3 training for TRIZ tools is showed in Fig. 3. (MATRIZ Level 1 training notes, 2014)

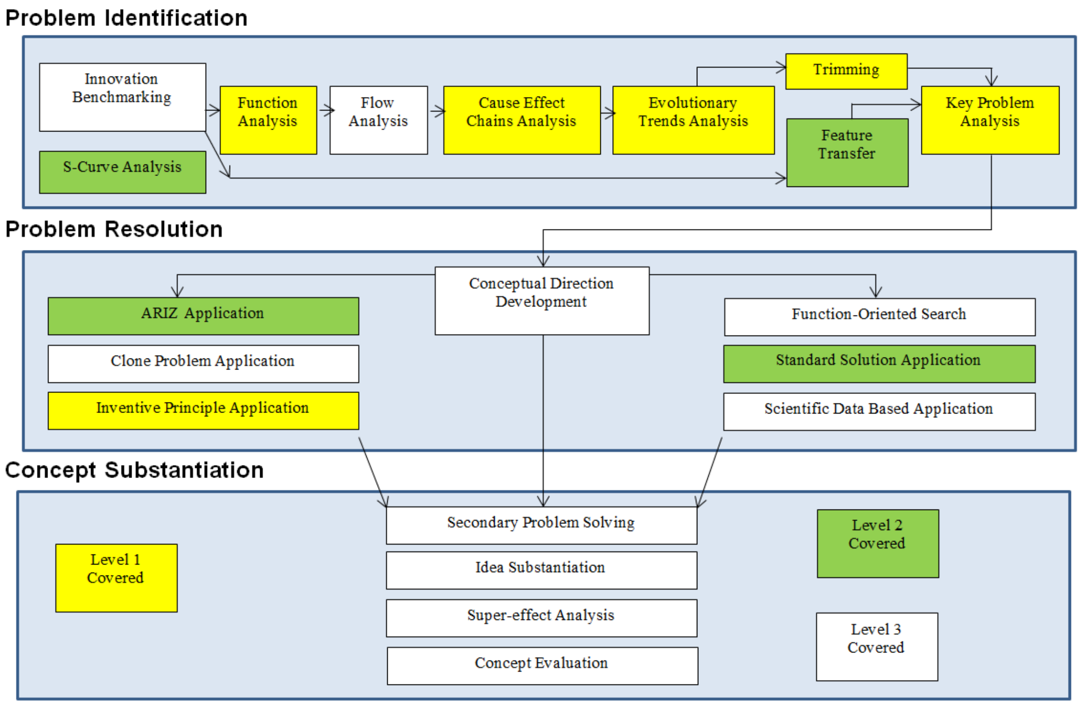

Fig. 3. Roadmap of TRIZ Training (MATRIZ Level 1, Level 2 & Level 3)

6. Integration of Quality Management System and Innovation Management System

Since both ISO 9001:2015 QMS and CEN/TS 16555-1:2013 InnoMS are following ISO Directives “Annex SL” High-Level Structure (HLS), the integration of both standard becomes more easy and compatible. The comparison of both standards’ clauses are shown in Table 1. The red color highlighted clauses are corresponded between both standards. The clauses in yellow color are important for implementation.

The clause 11 of CEN/TS 16555-1:2013 InnoMS is Innovation Management Techniques included “Strategic Intelligence Management”, “Innovation Thinking”, “IP Management”, “Collaboration Management” and “Creativity Management”. The details of Innovation management standards series are showed as follows:

- CEN/TS 16555-1, Innovation management – Part 1: Innovation Management System
- CEN/TS 16555-2, Innovation management – Part 2: Strategic Intelligence Management
- CEN/TS 16555-3, Innovation management – Part 3: Innovation Thinking
- CEN/TS 16555-4, Innovation management – Part 4: Intellectual Property Management
- CEN/TS 16555-1, Innovation management – Part 5: Collaboration Management
- CEN/TS 16555-1, Innovation management – Part 6: Creativity Management
- CEN/TS 16555-1, Innovation management– Part 7: Innovation Management Assessment

The Innovation Management techniques could be separated as System Level and Project Level. The combination of ISO 9001 and CEN/TS 16555-1 into QInnoMS is at system level. How to generate, evaluate and select new ideas, how to develop the project and ensure protection of results are at project level. The overall combined between QMS and InnoMS to be QInnoMS is showed in Fig. 4.

Table 1 Comparison of ISO 9001:2015 and CEN/TS 16555-1:2013

Clauses of ISO 9001:2015	Clauses of CEN/TS 16555-1:2013(E)
1. Scope	**1. Scope**
2. Normative references	**2. Normative references**
3. Terms and definition	**3. Terms and definition**
4. Context of organization - Understanding the organization and its context - Needs and expectations of interested parties - Determining the scope - Quality management system	**4. Context of organization** - Understanding the organization and its context - Needs and expectations of interested parties - Determining the scope - Management System
5. Leadership - Leadership and commitment - Policy - Roles, responsibility and authority	**5. Leadership for Innovation** - Inno Vision & Strategy Development - Leadership and commitment - Innovation culture - Roles, responsibility and authority
6. Planning - Actions to address risks & opportunities - Quality objectives and plans to achieve them - Planning of changes	**6. Planning for Innovation** - Actions to address risks & opportunities - Objectives and plans to achieve them
7. Support - Resources - Awareness - Competence - Communication - Documented information	**7. Innovation Enablers/Driving Factors** - Resources - Awareness - Documented Info - Competence - Communication - Strategic human resources - IP & knowledge management - Collaboration
8. Operations - Operation planning and control - Requirement of products and services - Design and development of products and services	**8. Innovation Management Process** - Development Inno Projects and Assessing the result
9. Performance Evaluation - Monitoring, measurement, analysis & evaluation - Internal audit - Management review	**9. Performance Assessment of the InnoMS** - Monitoring, measurement, analysis & evaluation - Internal audit - Management review
10. Improvement - Non-conformity and corrective action - Continual Improvement	**10. Improvement of the InnoMS** - Identify deviations and establish corrective action - Continual Improvement
	11. Innovation Management Techniques - Management of strategic intelligence, Inno thinking, IP, Collaboration and Creativity.

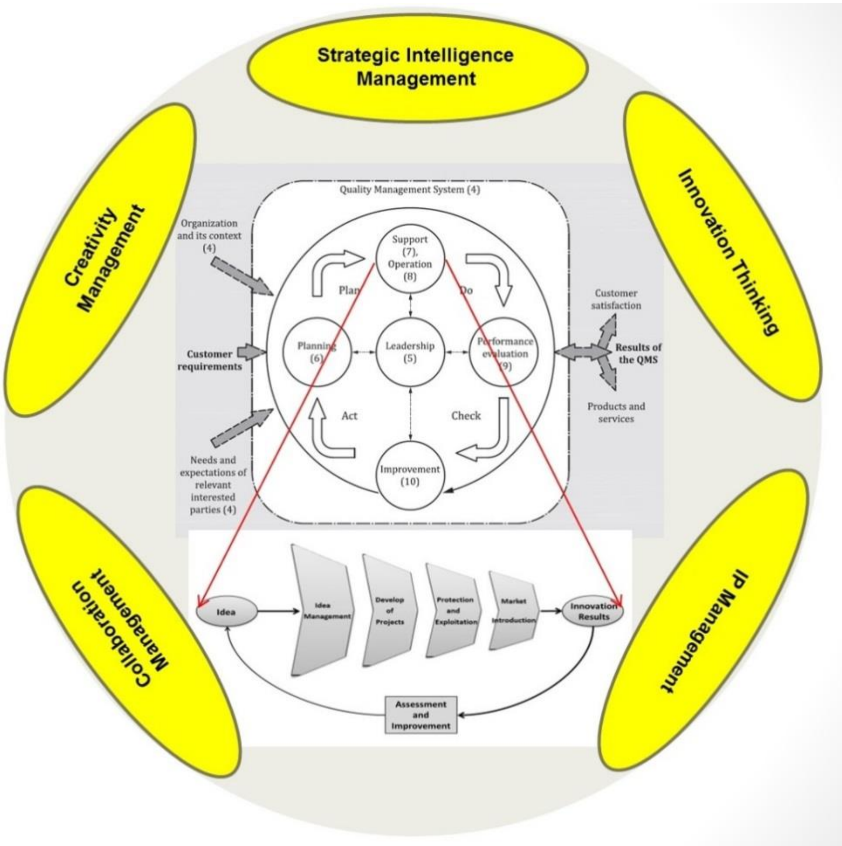

Fig. 4. Integrated Quality & Innovation Management System (QInnoMS)

7. Case Study and Discussion

Technology Support Centre (TSC) of Hong Kong Science and Technology Parks Corporation has employed TRIZ into the QInnoMS framework from Idea Generation to Innovation Result as preliminary case study. Ten members were selected to attend MATRIZ Certification Level 1 Training on 14, 15, 21 & 22 March 2014 and formed TRIZ promotion team (named TSC TRIZ Team – 3T) in order to solve different technical problems / projects. The first project named "Enhancement of IC sample amount and balance the Metal Tray weight". The procedure of reliability test is to put IC devices inside the holes of each metal tray which then stacked up in the environmental chamber. The test conditions are -65^{o}C to 150 ^{o}C, 15 mins dwell time and 1000 cycles. The maximum capacity of chamber (loading) is upto 2kg.

After nine windows exercise, we still focus on "Present" and "System & Sub-system". Then the Ideal Final Result (IFR) is identified as followings:

- i) Zero weight for sample holder
- ii) Hold large amount of IC samples
- iii) Fix IC samples orientation
- iv) Simply, No side effect and No cost, as well as, satisfied customer requirement.

We perform Function Analysis (FA) and the function model is created with Trimming (Rule – C). The key disadvantage is identified as heavy weight of metal tray by using "Cause and Effect Chain Analysis (CECA)". We selected related Engineering parameters and group with different contraction pair using IF…THEN…BUT statement. And then each engineer member found the contraction pair using engineering parameter and identified the Inventive Principles. Finally, we identify the most frequency Inventive Principles (IPs) which are IP 1 – Segmentation and IP 15 – Dynamic Parts and employ it to design the solution.

The final metal tray is separated from large one to small six places and reduces the weight of each tray. Moreover, the orientation hole is re-designed. The comparison of original metal tray and final metal tray parameter and result are recorded in Table 2 and Fig. 5. The result is found to be enhanced about 3 times of original one!

Table 2 The comparison of original metal tray and final metal tray parameters and result

Items	**Original Metal Tray (Parameters)**	**New Metal Tray (Parameters)**
Dimension of original holder and new holder (Length, Width and Height)	15cm*18.5cm*0.5cm	5cm*7cm*0.25cm
Weight of original holder and new holder	390g	52g
Number of sample held	270pcs	150pcs
How much of total sample could be handled per time in the oven?	270pcs*2 tray(per basket)*2 basket(per oven)= **1080pcs(of samples)**	150pcs*12 tray(per basket)*2 basket(per oven)= **3600pcs(of samples)**

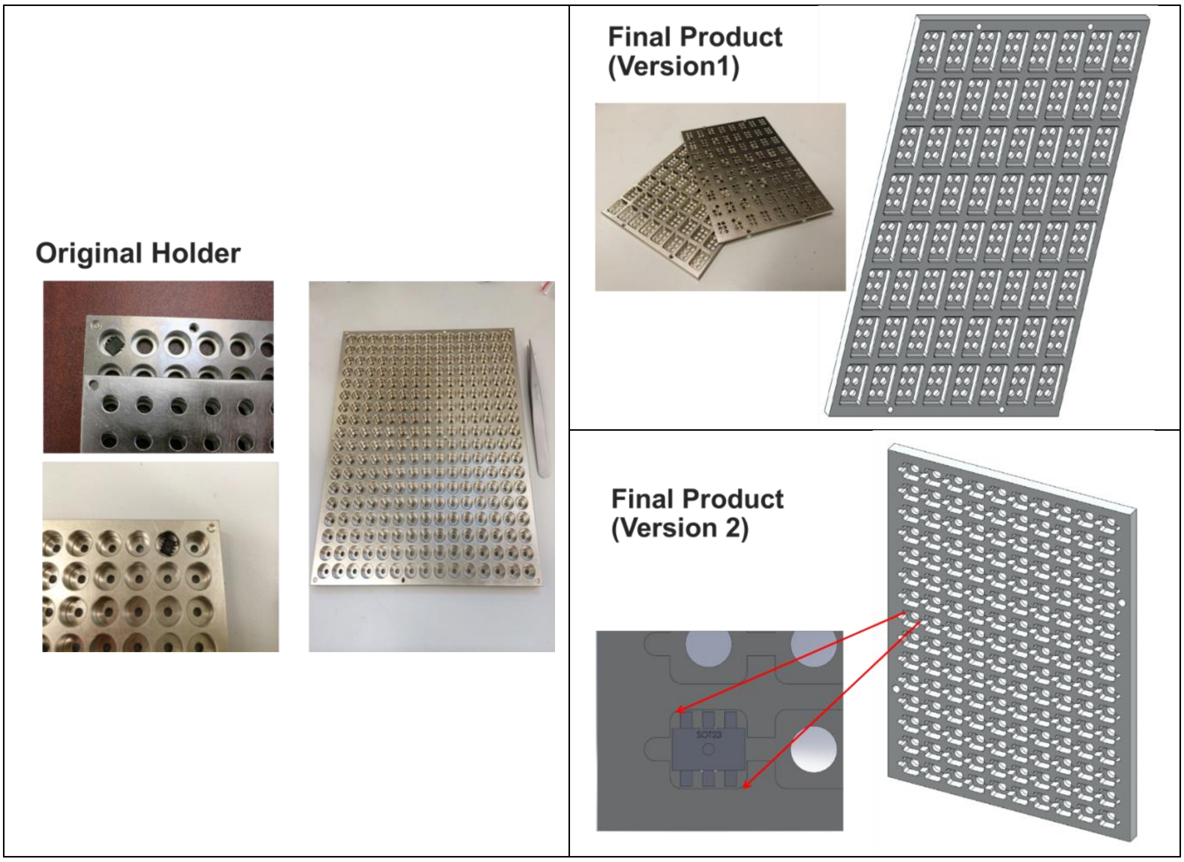

Fig. 5. The Original Metal Tray and Final Metal Tray designs

8. Conclusions

The integrated Quality and Innovation Management System (QInnoMS) model is still in conceptual level and those innovation management techniques are separated into system level and project level. We tried to use project level approach (such as using Design For Six Sigma (DFSS), Project Management (PM) and TRIZ, as well as, Extenics, etc.) to get some results first. TRIZ was selected for project level implementation and got a good result. Since TRIZ has no systematic framework, TRIZ Implementation through QInnoMS was employed to accumulate this experience. System Level of Innovation needs to understand context and develop innovation strategy, as well as, estimate the innovation capability of organization.

Lastly, QInnoMS needs to further study and establish the implementation methodology.

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POPULARIZATION AND APPLICATION OF TRIZ IN INTERNET ECONOMY

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Abstract

The development of information technology has greatly improved people's information processing capability and the utilization efficiency of information, which has accelerated the progress of science, technology and innovation. In addition, as the Internet has accelerated information spread in the world, the query and utilization of knowledge has been facilitated. The Internet serves as a useful resource helping people search worldwide for solutions to their problems. However, when no solutions can be found on the Internet directly, TRIZ is an ideal innovation tool. Nowadays, the knowledge of TRIZ can be learned from the internet, but how to effectively use TRIZ and TRIZ software or tools can only be taught through conventional ways such as face-to-face training.

According to the above discussion, we propose a new way of promoting TRIZ ---- establishing an innovation platform to integrate various services including TRIZ software and tools, training, consulting, etc. With the help of the platform, users can learn how to use TRIZ, carry out TRIZ consulting projects and use TRIZ tools until they get the innovative solutions they desire.

Keywords: TRIZ training, internet, Technology Evolution

1. The influence of market environment on technological innovation of companies

It has been nearly 40 years since China implemented the reform and opening-up policy, and the competitiveness of Chinese companies has been strengthened considerably. They are making progress in catching up with the advanced companies in the world and in some aspects have surpassed them. During all this process, technical innovation has played a critical role.

In the early 1980s, Chinese companies were generally small in scale and backward in technology. The products produced by them could not compete with those produced by foreign companies either in production volume or in quality. At that time, instead of innovating in technologies, Chinese companies usually took the strategy of introducing advanced technologies from foreign companies and then making improvements. The reason was that tremendous quantities of manpower and material resources were required for the development of core technologies and technological breakthroughs could hardly be achieved in a short time.

Many companies took a simpler mode of technology development -- integrated innovation. They introduced several advanced technologies from abroad and made new products by integrating these technologies. In this way they only needed to develop some supporting technologies. The advantage of this mode was that new products could be developed in a short time to without many professional or technical efforts. The disadvantage was that companies had to pay a lot of money for technology transfer. Their profits were thus undermined. What's worse, as the core technologies were still in the hands of foreign companies, the Chinese companies had no chance of catching up with and surpassing their rivals. Instead, in order to maintain their market presence, they had to keep buying new technologies from foreign companies. Integrated innovation enabled Chinese companies to expand their production scale and meet the huge consumption demand of the market. With this technology development mode, China has become a "word factory" since 2000. However, it is merely a manufacturing workshop with no core technologies.

With the expansion of the production scale, Chinese companies came to realize that they had to master independent core technologies, or else it was a daydream to achieve further development. They found out that the only way to gain market initiative was to break away from the dependence on foreign technologies. "Innovation methods are the prerequisite of independent innovation," that is the slogan of innovation proposed by the Chinese government in 2008. Since then, Chinese companies have kept introducing innovation theories, learning innovative thinking and trying hard to innovate. TRIZ is the most popular and efficient theory for innovation. Therefore many companies are willing to learn TRIZ and wish to efficiently solve, with the help of the theory, the most difficult technical problems they encounter.

2. The influence of the Internet on technological innovation of companies

The Internet has its roots in the ARPANET (Advanced Research Projects Agency Network) of the United States. It is an enormous worldwide network of a unified logic which links numerous smaller networks with a common set of protocols. The Internet has the following characteristics:

1. Resource sharing: e.g. newspapers, books, CDs;
2. Unrestricted by time and space: e.g. online trading;
3. Real-time interactive: e.g. web chat, interactive TV;
4. Personalized: to meet the individual needs of everyone;
5. Friendly: easier to learn and use;
6. Fairness: the same platform for people all over the world.

The Internet boosts the economic development of various countries in the world. The number of Internet users in the developed G20 countries grows 8% annually. The contribution of the Internet to their national GDP growth reaches 5.3%. In the developing G20 countries the growth rate reaches up to 18%. It is estimated that during 2010-2016, the scale of Internet economy of the G20 countries will double and create 32 million new jobs. The technologies developed on the basis of the Internet satisfy different needs of the society:

- Network information access technologies, including network news, search engines, information classification, information aggregation and knowledge sharing, meet the needs for information;
- Electronic commerce, including B2B, B2C, C2C and O2O, meets the transaction needs of people;
- Internet communication, such as instant messaging, personal spaces, social networks and network forums, meets the communication needs of people;
- Internet entertainment applications, such as online games, network literature and network videos, meet the entertainment needs of people;

- Electronic government applications, such as G2G, G2E, G2B and G2C, meet the needs of the government.

However, there are no Internet applications that fully meet the needs of innovation. In our view, the Internet mainly influences corporate technological innovation in two aspects: it changes the mode of commodity trade; it improves the information retrieval efficiency.

The traditional economy centers on market supply while consumer sovereignty is usually neglected. That is mainly caused by information asymmetry. There are no efficient ways for companies to learn more about consumers, which gives the companies, rather than the consumers, an advantageous position. The rise of the Internet has flattened the information hierarchy and facilitated communication among people. Large amounts of high-quality information about consumers and companies can be found on the Internet, and the cost of searching for such information has been greatly reduced. Consumers can easily find the products and services they need; and companies can acquire more useful information to improve or develop new technologies. On the other hand, with the development of the Internet, the time and space gaps between companies have disappeared gradually, making the competition among companies more intense. Information about any new product or technology developed by a company gets circulated in a short time. Its competitors will soon launch similar products to compete with it. Companies can find the information about competitors' products on the Internet, compare their products with the competitors' and make their product plan accordingly. In order to maintain their market position, all companies have to speed up the pace of innovation and increase their investment in technological innovation.

The Internet has also greatly improved the efficiency of scientific and technological information search. A large amount of scientific and technological information is stored on the Internet and it is free. Everyone can retrieve and use such information. With the help of the search engines, companies are able to acquire almost all the scientific and technological information they need in technological innovation. Apart from scientific and technological information, information about innovation knowledge and tools can also be found on the Internet. Such information is presented in forms of electronic books, project cases, lecture videos, etc. Therefore, the Internet can help companies acquire the known information and knowledge they need.

However, unknown innovation solutions cannot be found on the Internet. Innovation solutions can be created only by the corporate research staff or through the service of the innovation consulting firms. For example, a Chinese company developed a new product, but the core technology of the product is monopolized by a foreign company which has applied for patent protection for the technology in various global markets. If the Chinese company opted to export the product, it would be sued for patent infringement. If it opted to sell the product in the domestic market, it would face intense competition. How did the Chinese company get out of the dilemma? First, the research staff of the company searched for information about the patented technology on the Internet and found out the key patent. Then, with the help of an innovation consulting firm, the company worked out a new solution which successfully circumvented the patent. This case is typical in illustrating the common path of technology innovation adopted by Chinese companies. They usually search for scientific and technological information on the Internet by themselves, and then create innovation solutions by means of TRIZ and other innovation methods. Therefore, with the development of the Internet, the way in which companies use innovation methods has changed, and their requirements on innovation consulting services have been raised. Traditional innovation training can no longer meet the needs of companies. Innovation consulting services need to be adjusted to better satisfy the actual needs of companies.

3. TRIZ promotion mode in the Internet economy

The traditional training mode has been around for decades. It is mature and perfect. In this mode, trainees usually gather together for face-to-face training and consulting projects are carried out under technical consulting contracts. Offered in fixed time and fixed place, the training is featured by highly efficient face-to-face teaching and in-depth discussion. In order to ensure the quality of teaching, the class size should be 20-30 trainees per class. More classes should be arranged for more trainees. In addition, the trainees in the same class should not differ greatly in learning ability. Otherwise some of the trainees may have difficulty in learning while the others may think the course is too easy.

The Internet unfolds new possibilities for the promotion of TRIZ. The Internet has changed the operation mode of the traditional economy as well as the path of corporate technological innovation. Thus the requirements of companies on external innovation services have changed. More and more companies are no longer satisfied with the traditional standardized training. Instead, training programs that are more targeted, more flexible and more adaptable to the development of companies are needed. According to the characteristics of the companies in the Internet economy, the mode of TRIZ promotion should be changed from standardized training to customized training; from systematic training to embedded training; from elite training to universal training; and from simply knowledge teaching to practical application.

3.1. Changing from standardized training to customized training

In the traditional innovation training, consultants provide standardized training courses for companies. In earlier time, companies might have never organized innovation training before, so innovation methods were a completely new field for them. At that time, standardized courses could satisfy their needs. But nowadays almost all companies have organized training in management, technology, quality control and many other aspects. Even if they have never carried out innovation training, they know clearly what problems they have and what should be done to solve the problems. Their demands are specific and targeted. They eagerly hope that training courses can be adjusted to better satisfy their needs.

3.2. Changing from systematic training to embedded training

For traditional innovation training, complete course systems and corporate-oriented application systems have been developed. Unfortunately, such systematic training failed to effectively promote innovation methods in companies. As companies usually have their own management systems, they would rather integrate innovation methods into their existing systems than set up wholly new systems. In addition, innovation tools have different applications in different departments of a company (e.g. the R&D department, the production department, the administration department, etc.). Therefore, innovation training courses should be more flexible to satisfy the demands of various departments and more adaptable to the existing operating system of the company. Some South Korean companies have set an example of embedding innovation methods into their own systems.

3.3. Changing from elite training to universal training

In the past, only a small number of employees in a company could take part in developing patented technologies and products, which was regarded as high-level innovation. In addition, employees who took innovation training were required to have a good educational background and substantial work experience. With the development of the company, all aspects of its operating system need to be improved and optimized, requiring more employees to master innovation methods. Therefore, universal training that targets average employees should be arranged instead of elite training.

3.4. Changing from simply knowledge teaching to practical application

Essentially, what companies need is not innovation methods, but the profits generating from the application of innovation methods. Only when the trainees finish classroom training, tool practice and trial application and acquire enough work experience, can they give full play to innovation methods and earn profits for their companies. The traditional way of promoting innovation methods focuses on knowledge teaching, and no longer suits companies in modern times. In order to meet the needs of modern companies, application and practice must be stressed in innovation training. Application projects can be carried out simultaneously with training courses. That requires the consultants to have more extensive experience and master more innovation roadmaps.

Based on the above analysis and according to the development of the Internet and the demands of companies for technological innovation, we propose a new promotion mode of Internet + TRIZ. In this mode, an innovation platform is built on the basis of the Internet and integrates various services of TRIZ training, consulting, innovation tools and software. Users can learn TRIZ knowledge and improve their innovation ability on the platform. They can also use a variety of tools to find innovative solutions for real projects. On this platform, each course or tool is an independent consulting unit. In the meantime, these units are correlated with each other and can be combined freely.

There are several advantages of this platform. ① The innovation tools can be used more flexibly to satisfy the needs of companies in different industries and of different sizes. ② Unlike the traditional classroom training, the platform is not limited by time and space. Therefore, it can provide training services for people in different places at the same time, or for the same people in different periods of time. ③ On this platform users can give reviews about independent consulting units. These reviews (e.g. from one to five stars, with comments) would help new users select units that fit their needs more exactly. ④ As the TRIZ community grows in China, this platform will attract more and more users and become increasingly gluing.

The new mode maintains the advantages of the traditional TRIZ promotion mode, but is more flexible and efficient than the traditional mode. We believe it can better meet the needs of modern companies and improve the efficiency of corporate technological innovation.

4. Conclusion

Market demands are the driving force for corporate innovation. At the beginning of China's reform and opening up, the market was in short supply, and companies never worried about selling their products. They were more concerned about expanding production capacity than technological innovation. However, since the year of 2000, the Chinese market has been in oversupply. An enormous number of products are being exported incessantly to foreign countries. Thus Chinese companies are facing intense competition from foreign companies. In order to survive, Chinese companies have to learn innovative methods and undertake innovation activities. The development of the Internet has changed the market environment further more. Market competition has become fiercer, forcing companies to accelerate product update frequency, raise product quality and improve production efficiency. Therefore, companies must use innovation methods to greatly improve their ability and efficiency of solving problems. The traditional TRIZ promotion mode no longer meets the demand, and the

Internet + TRIZ mode is the only way out. Similar to the evolution of technology systems, the promotion mode of TRIZ will evolve to be more flexible and adaptable to the demand.

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PROBLEMS AND COUNTERMEASURES IN PROMOTING TRIZ IN CHINA

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Abstract

Compared with Korea and Japan, China was relatively late in promoting TRIZ. During the first several years of the 21st century, only a few large companies implemented TRIZ and organized TRIZ training and project workshops. Among them was Baosteel, which started to organize TRIZ training from 2007. Large-scale promotion started from 2008. At that time, the Chinese government realized the importance of innovation, and began actively promoting various innovation methods and theories including TRIZ. In 2012, we started to offer innovation courses at primary and middle schools. TRIZ has brought surprise for both large companies (eg. Baosteel) and students of 8-12 years old. However, there have been problems during the promotion of TRIZ. For example, some companies were too eager for short-term results and did not address efforts to establish sound training and innovation systems. Some schools expected their students to win awards and did not care much about what the students really learned. These problems have hindered the effective implementation of TRIZ. As a result, many companies abandoned TRIZ after 1 or 2 rounds of training. As educators and practitioners of TRIZ, we hope to find solutions to these problems and help better promote TRIZ in China.

Keywords: Promoting TRIZ, TRIZ training, TRIZ Certification

1. Problems in promoting TRIZ in China

TRIZ started to spread to China at the end of the 20th Century. In the first years, TRIZ was disseminated slowly in the country, and only a few companies were willing to learn and use it. In 2008, the Chinese government comes up with an initiative of building an innovative country. Since then, government structures and organizations at all levels and specialists from many industries began to learn and promote TRIZ. Thus TRIZ and innovation has become the most popular words in China. Nowadays more and more Chinese companies have realized that TRIZ is an efficient tool for innovation. In recent years, institutions of higher learning in China are also active in offering TRIZ courses. TRIZ courses for primary and secondary school students have been developed and put in the practice.

The common format for Chinese enterprises to promote TRIZ is as follows: first, the selected specialists are receiving the basic knowledge of TRIZ from consultants; secondly, project consulting is conducted in which the trainees are proposing the problems they encounter in their work and the consultant instructs them to solve the problems by using TRIZ; third, the management department of the company are evaluating created concepts. After the evaluation, a new round of training is launching for the new trainees at the same format. Unfortunately, many companies are ending the TRIZ training after one or two rounds of training. They are not integrating TRIZ into the process of scientific research management, and the trainees no longer use TRIZ to solve problems after training. Factors preventing these companies from further applying TRIZ include inadequate activity of trainees, inappropriate projects selection for consulting, improper assessment criteria, low interest of companies managers in TRIZ implementation, etc. In our view, the most important thing for companies to effectively use TRIZ is that they must have a deep understanding of the thinking mode of TRIZ and master the general rules of solving problems. Only in this way they can make better use of TRIZ and improve the level of innovation. The TRIZ courses for company specialists, college students and adolescents are just tentative and far from perfection. A comprehensive framework should be designed and a complete teaching system and curriculum should be established in the promotion of TRIZ in colleges and among adolescents.

2. Proposals for promoting TRIZ in China

2.1 Promoting TRIZ in enterprises

The goal of promoting TRIZ in enterprises is to help employees master innovative tools and bring greater benefits for enterprises by using these tools. In a company context, TRIZ should be regarded as the necessary knowledge and skill for employees who are engaged in research and development, engineering and other technical activities. Moreover, it should be imbedded in their working habits and be an essential tool for innovation. Only in this way, can companies achieve innovation of higher levels. To this end, enterprises should take measures from three perspectives, namely, the process, people and management.

Process: This example of a TRIZ Implementation Plan is based on our experience and on the experience of our colleagues. It represents the first round of TRIZ implementation for a company. After first round completion, the company has internal TRIZ consultants and engineers prepared to use TRIZ for successful projects creation and problem solving. This step also prepares the company for continued TRIZ implementation using its own TRIZ specialists. The TRIZ Implementation Plan for companies varies depending on real conditions and requirements.

The TRIZ Implementation Process Contains the Following Steps:

1. TRIZ overview lecture for the company management team, including top R&D managers
2. Creation of a TRIZ Implementation Plan and approval by company ’ s top management team
3. Review and selection of projects for further development
4. Basic TRIZ training for project team members
5. First workshop for all selected projects: project scenario creation for each project
6. Advanced TRIZ training for project team members
7. Workshop sessions for all selected projects
8. Projects results review
9. Mastery TRIZ class for selected team members and leaders, candidates for the company’s TRIZ consultants/teacher
10. Steps 3 through 8 are repeated 3 to 4 times with the candidates for the company’s TRIZ consultants/teachers

11. Basic and Advanced TRIZ training topic preparation to the company, including case studies from the best projects results
12. Decision making about establishing the company’s Center of Innovation

People: Although TRIZ is an innovative tool, it is useless without users. Ability of innovation to produce good results does not depend on the TRIZ itself, but on its users. Therefore, the results of an innovation are determined by the user's mastery of TRIZ. For the successful promotion of TRIZ in a company, it is very important to choose the right people to use TRIZ. The users of TRIZ are required to be rigorous not only in thinking but also in working. They should strictly follow the procedure of TRIZ and never take short cuts. TRIZ users in enterprises can be classified into the following three categories.

1. TRIZ experts, who are responsible for consulting, tutoring and promotion of TRIZ.
2. Key R&D staff, which is the technological innovation backbones of an enterprise and also the most suitable group for learning and using TRIZ.
3. Technicians on the production sites, who have substantial experience in problem solving. Once they master TRIZ, these technicians will play a greater role.

Management: The promotion of new methods cannot do without the support of management. For the effective promotion of TRIZ, leadership support, internal training and innovative cultural atmosphere is necessary to perform the following steps:

1. The promotion of the TRIZ should be carried out from top to bottom. It is a general rule that the promotion of any new things should be carried out from top to bottom. It is true especially with the promotion of innovative methods such as TRIZ. Without vigorous support of the leadership, the promotion of TRIZ can be a mere formality and will never bring forth a fundamental change to the company. Only the energetic support by the management can encourage employees to use TRIZ and other innovation methods
2. Systematic guarantee of supporting of active employees. Many multinational companies designate full-time staff to promote TRIZ. They also set up an incentive mechanism to guarantee the benefits of employees who are trying to learn and use TRIZ. In addition, with an appropriate system, TRIZ can find a continuous application in a company context and be gradually integrated into the corporate research & development system. Thus TRIZ can be a standardized tool for innovation.
3. Internal training. Usually companies introduce TRIZ by hiring consulting firms or TRIZ experts to carry out TRIZ training. Companies need to pay a lot of money for these external trainers while the influence may be fairly narrow. Therefore, external training is only suitable for a small range of core TRIZ users, but not for the entire company. Thus in the early stage of TRIZ promotion, companies have to prepare own TRIZ experts, as internal trainers which will train necessary number of company's employees later.
4. Atmosphere of innovative culture. Innovation should become a part of a company's culture. Companies should create an atmosphere of innovation and integrate innovation into the corporate values. Such an innovative culture can encourage employees to use their wisdom, imagination and creativity for greater contribution to the technology development of the company.

2.2 Promoting TRIZ in colleges and universities

Innovation education should be focused to foster innovative talents, and should have a comprehensive curriculum system to help students develop innovative consciousness. In China, the education sector has now realized the importance of innovation education, but the proportion of colleges and universities offering TRIZ courses is still low. Only a few colleges and universities provide pilot or tentative TRIZ courses.

The TRIZ courses offered by colleges and universities in China and abroad are mainly delivered in the following forms:

1. TRIZ is taught as a part of the innovative design course;
2. TRIZ is taught as a part of the innovation and entrepreneurship course;
3. TRIZ is taught as an independent free or distributional elective course;
4. TRIZ is promoted in forms of lectures or short-term training;
5. TRIZ is promoted through student associations.

Our intention for the future is to create and introduce curriculum for undergraduate and graduate programs “Technology for Innovation" based on TRIZ. It is a new academic specialty with a goal of professional preparation of innovative specialists for systems evolution and development. “Technology for Innovation" will be interdisciplinary program individually adjusted/adapted for each college and university.

These specialists will apply their unique knowledge and practical skills in many diverse areas of science, business, industry and education, including but not limited to:

1. teachers in kindergartens and in school for kids preparation for the real, creative and successful life
2. teachers, researchers, and scientists in colleges, institutes, and universities for preparation of specialists in the technology and systems development and evolution.
3. scientists, researchers, and engineers in different domains of industry and sciences for increasing the speed of balanced development of China.

2.3 Promoting TRIZ among adolescents

Human has congenital features to learn and collect new knowledge and use it creatively without any limitation and psychological barriers. Their creative potential is gradually developed and activated reaching the peak when they are in junior high school. After that, the continuing accumulation of information, influence of environment and appearance of psychological barriers lower the level of creativity and innovation ability. Thus with the increase of age, knowledge and experience, people tend to develop a fixed and standardized way of thinking. People gradually lose their creative imagination and have been turned into a hostage of their own psychological inertia at this stage of adulthood.

TRIZ should be promoted among adolescents as early as possible. TRIZ is an ideal tool to lower level of psychological inertia and to develop creative imagination. TRIZ will teach kids to view, analyze and solve problems by using TRIZ technology for innovation and knowledge received in school. Thus TRIZ will help to improve practical and innovative thinking skills of adolescents.

The purpose of promoting TRIZ among adolescents is to avoid the negative effects brought about by knowledge and experience and improve their imagination. TRIZ analyzes problems from various perspectives, and then imagines and designs future technology systems according to the laws of technology development. Therefore, the innovation education for adolescents should focus on fostering their ability of understanding problems from various angles, helping them find out the essential aspects of things, and improving their imagination. Not limited by age and knowledge, these abilities can be developed from an early age (4 or 5 years old) by means of appropriate training.

It should be noted that adolescents cannot accept abstract theories and methods like TRIZ as well as adults do. What they need is concrete and perceptual knowledge which can improve their innovation ability. For this reason, we proposed to infiltrate TRIZ ideas little by little into the minds of adolescents by way of playing games. Therefore, liberal imagination and systematic observation are the main approaches of TRIZ education for adolescents.

3. Conclusions

TRIZ is a highly efficient innovative tool that can change people's thinking habits. As a highly efficient tool for innovation, TRIZ can change people's thinking habits. Many companies and schools in and outside China are actively and fruitfully promoting TRIZ. In order to promote TRIZ more effectively, we have proposed different TRIZ promotion approaches for people of different age groups and levels.

1. In enterprises, the promotion process, people and management support are critical to the successful promotion of TRIZ;
2. In colleges and universities, a specialty of innovation should be established and perfected to more systematically teach students the theoretical knowledge of innovation.
3. In primary and secondary schools, TRIZ courses should be designed and offered to improve the innovative thinking ability of adolescents.

Compared with the foreign countries, China introduced TRIZ relatively late and is still learning and exploring to use the theory. However, we have reason to believe that, as long as appropriate promotion approaches are adopted, Chinese companies and schools will soon deepen their understanding of TRIZ and improve their ability of applying the theory.

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PRODUCT-ORIENTED MPV ANALYSIS TO IDENTIFY VOICE OF THE PRODUCT

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Abstract

This paper addresses one of the biggest problems of any new product development (NPD): ideas generated for new products often do not yield successful products. One of the main reasons for this is that the voice of the customer (VOC), used as the main input for generating and screening new product ideas, frequently reflects customers' wants and needs incorrectly. In this case the new product, if developed, will fail on the market. On the other hand, while the new product may offer features and functionality that do not fully satisfy the target customers' needs and wants, they may be appreciated by other group(s) of customers. In a typical NPD process the idea for such a potentially successful product does not pass screening and, so, will never be implemented. This problem may be solved by supplementing the VOC with the TRIZ-derived voice of the product (VOP), which reflects a product's objective needs and wants. To identify the VOP, TRIZ developers proposed the Main Parameters of Value (MPV) analysis. Yet the existing algorithm for MPV analysis is still 'customer-oriented': it merely expands the VOC by including customers' latent needs and wants and attempts to satisfy this VOC through product improvements. In this paper, the author is proposing a product-oriented MPV analysis aimed at a more holistic identification of the VOP. This makes it possible to discover the new product's latent capabilities and identify the right customers for the product. The paper includes brief case studies illustrating the proposed approach.

Keywords: Main parameters of value; MPV; new product development; NPD; TRIZ; voice of the customer; VOC; voice of the product; VOP.

1. Introduction: Existing MPV Analysis is Insufficient to Identify the VOP

Already in the early 2000s, basic classical TRIZ tools such as SU-Field analysis, Contradiction Matrix, and Function Analysis were being recognized as useful tools to integrate into the Six Sigma roadmap [1]. Other researchers went further, investigating such opportunities for integration in more detail [2].

As a result, Design for Six Sigma (DFSS) and Service DFSS finally adopted basic TRIZ instruments at the concept generation stage during new product development (NPD) [3]. In so doing, the probability of generating a feasible concept for the new product is enhanced, and the technical risks involved in the DFSS process decrease.

Nevertheless, as the voice of the customer (VOC) is the main input for generating and screening new product ideas, currently implemented TRIZ tools cannot reduce the risk of generating a wrong idea for the product during the first stage of the DFSS NPD process. Incorrectly identifying the VOC is a common reason for new products failing on the market.

In order to further reduce the business and technical risks associated with an NDP, the author has suggested integrating not just the basic tools, but also more modern TRIZ tools into all stages of NPD - including Stage-Gate [4] and DFSS [5] processes.

The most important tool to reduce the risk of generating a wrong idea for the new product is the voice of the product (VOP) [6], which reflects a product's "needs and wants" and supplements the VOC.

To identify the VOP, TRIZ developers have proposed an algorithm for main parameter of value (MPV) analysis [7, 8], which involves (1) Function Analysis of the product being improved and of the target customer, and (2) the Trends of Engineering Systems Evolution (TESE) analysis, including S-curve analysis for the product's important parameters of value.

In practical applications of modern TRIZ, this tool has been successfully used for:

- Converting business challenges into a set of underlying technical problems [9, 10];
- Identifying the target customer's latent needs that the new product can satisfy [11].

Still, the MPV analysis in its existing form is more of an extension to VOC rather than a true VOP tool because it focuses only on those product's needs and wants that may satisfy the target customer's needs and wants (including latent ones). Sometimes, however, the product may offer features/MPVs that are useless to the target customer, but could be extremely useful to other customers ("latent customers"). The existing MPV analysis does not address the needs and wants of latent customers.

In order to resolve this issue, the author has proposed a top-level algorithm for identifying the VOP and combining it with the VOC [12]. The algorithm involves two types of MPV analysis: Customer-Oriented and Product-Oriented MPV analyses as shown in Fig. 1.

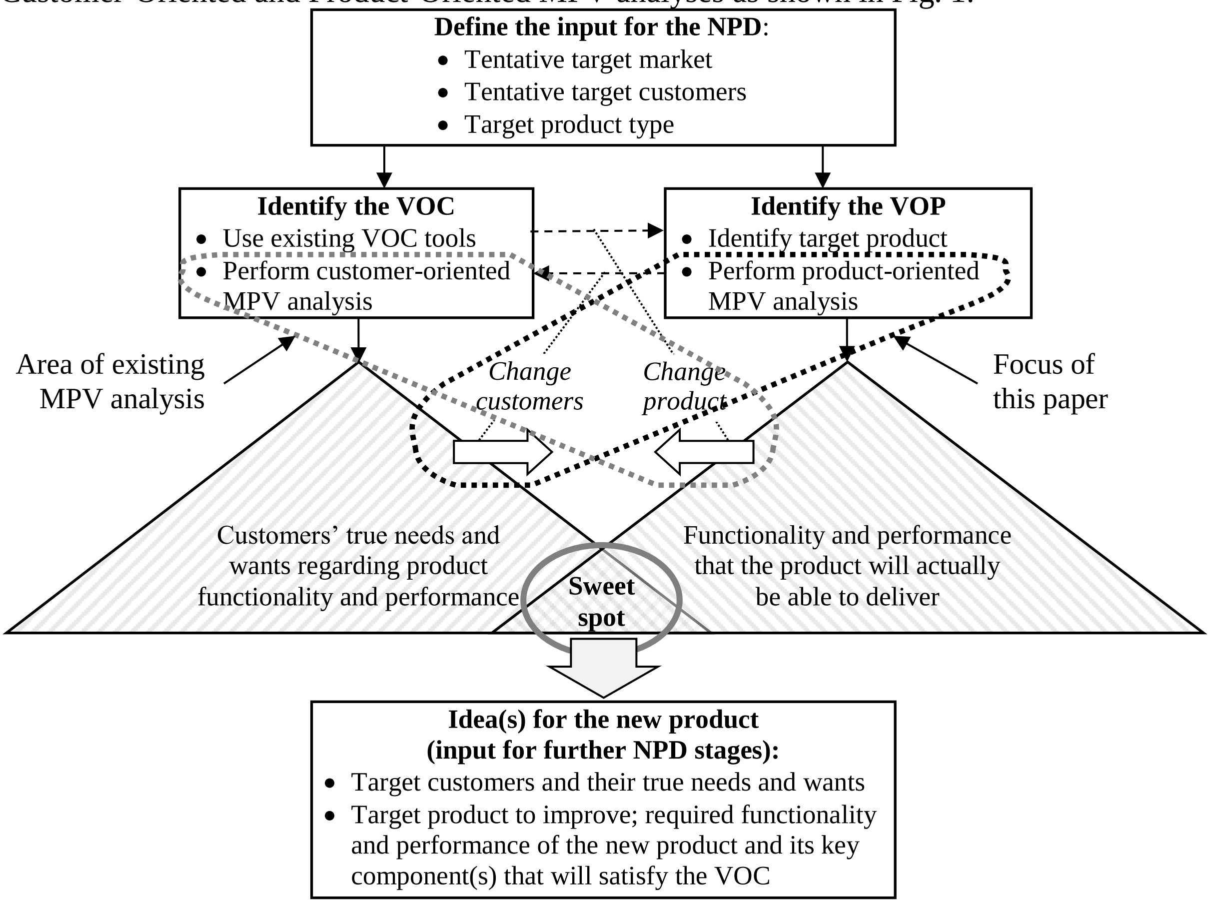


Fig. 1. Combining the VOC and the VOP [12]; the focus of this paper

In Fig. 1, the customer-oriented MPV analysis is essentially the same as the existing MPV analysis [7, 8] and, actually, refines the VOC, while the product-oriented MPV analysis reveals the product's true needs and wants. This paper will focus on the details of the product-oriented analysis as well as on the nuances of combining the VOC and the VOP.

2. Methods Employed

In order to introduce a product-oriented MPV analysis, the author has applied the functional approach as illustrated in Fig. 2.

As seen from Fig. 2, the product-oriented MPV analysis is performed using a different functional model than that used for the customer-oriented MPV analysis:

- Customer-oriented MPV analysis considers a customer-centric function model (Fig. 2a) that allows for identifying a product's latent useful functions/MPVs by transferring its useful functions and features from supersystem components (e.g. from other products that the customer uses) to the product to be improved.
- Product-oriented MPV analysis considers a product-centric function model (Fig. 2b) that allows for identifying latent customers, by isolating them from the supersystem, and a product's latent useful functions/MPVs that these customers will appreciate.

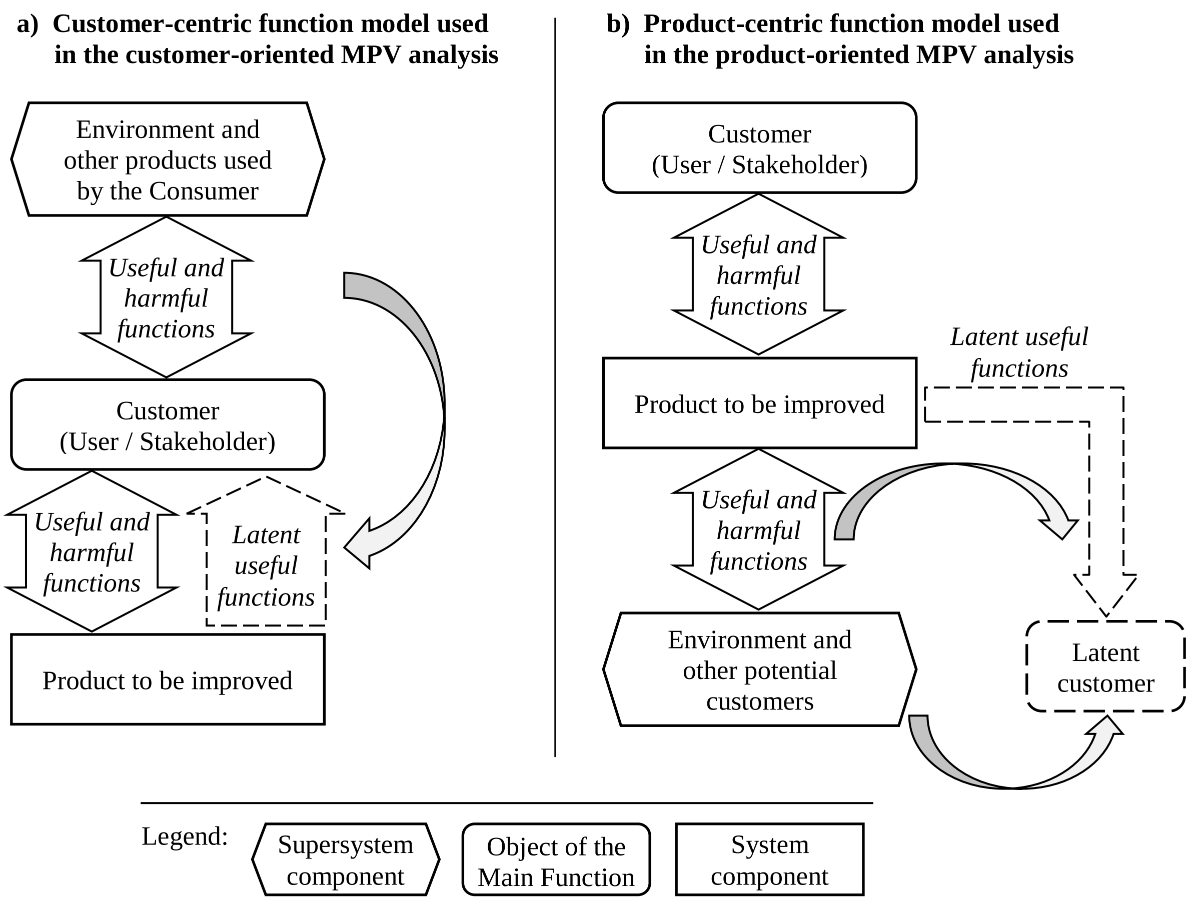


Fig. 2. Function models employed in customer-oriented and product-oriented MPV analyses

In order to combine the results of the VOC and the VOP so as to maximize the sweet spot between the two (see Fig. 1), fragments of the Kano analysis [3] and elements of the correlation analysis are employed.

3. Results: Proposed Algorithm for Product-Oriented MPV Analysis

As shown in Fig. 1, prior to performing the product- and customer-oriented MPV analyses, the following items have to be defined: (1) target product (or at least the target product type); (2) target market / market niche; (3) target customers and use case scenarios.

Also, the VOC must be collected from the target customers before doing further analyses.

Table 1 shows the top-level algorithms for the product- and customer-oriented MPV analyses.

Table 1

Top-level algorithms for the product- and customer-oriented MPV analyses

Step #	Customer-oriented MPV analysis	Product-oriented MPV analysis
1	Build ***customer-centric*** function models (Fig. 2a) for each target customer, market and use case scenario	Build ***product-centric*** function models (Fig. 2b) for each target customer, market and use case scenario
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 MPV candidates resulting from both product- and customer-oriented analyses	
5	Identify the ***customer's*** "MPV profile", i.e. refined VOC, for each target customer, market and use case scenario	Identify the ***product's*** "MPV profile", i.e. the VOP (if needed - for each target customer, market and use case scenario)
6	Identify/calculate the correlation between product's and customer's MPV profiles	
7	If the correlation is weak - identify ***latent MPVs*** that make the product's MPV profile better correlate with the customer's or select ***another target product that better matches the VOC***	If the correlation is weak – select ***another target customer*** whose MPV profile better correlates with the product's profile or identify ***latent customers that better match the VOP***
8	Compile the final list of target customers and refined MPVs of the target product	

Further in an NPD process, the MPV analysis described in Table 1 is followed by:

- Translating the identified MPVs into underlying physical parameters of value by using, for example, Quality Function Deployment (QFD) tool [3];
- Identifying the Key Problems that prevent achieving high MPV performance, which can be done using Cause and Effect Chain Analysis (CECA) of disadvantages [15];

- Resolving the Key Problems using problem solving tools from modern TRIZ, e.g. Function Oriented Search (FOS) [16];

- Developing a concept and a business case for the new product.

All of these post-MPV analysis steps, however, are beyond the scope of this paper.

In Table 1, steps 1 and 8 of the proposed algorithms seem to be self-explanatory and do not require clarification. Steps 2 through 4 have the same sense as in the existing MPV analysis [7, 8] and, therefore, will not be explained here.

Steps 5 through 7, however, need further elaboration as they are new to MPV analysis.

3.1. Clarification of Step 5: Customer and Product MPV Profiles

The customer and product MPV profiles to be identified in Step 5 include a list of MPV candidates selected at Step 4, and the corresponding array of their ranks reflecting the importance of these MPVs. In fact, these profiles are the mathematical characteristics of VOC and VOP.

For both customer and product profiles the list of MPV candidates is the same, while the arrays of MPV ranks may be different - reflecting the difference between the customer's and product's needs and wants.

In order to rank the MPV candidates, the author proposes categorizing them as Dissatisfiers, Satisfiers, Delighters or Indifferent using the same approach as in the Kano model [3]. Then, each category is ranked according to its relative importance as shown in Table 2.

Table 2

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	

For the customer profile, the definitions of MPV categories are the same as in the Kano model; and MPVs are attributed to a particular category based on the identified VOC.

For the product profile, the definitions relate to the results of an S-curve analysis [13, 14]: the MPVs that have to be improved urgently (dissatisfiers) and those that can be improved later (satisfiers) are determined depending on the current stage of the product's evolution (Fig. 3).

For example, Fig. 3 shows that the most important task at early stages of the evolution is to maximize the performance-related parameters, which at these stages are dissatisfiers. Reliability and cost-related parameters remain satisfiers throughout the early stages of evolution, while latent MPVs remain delighters right up until the product matures.

As seen from Fig.3, the NPD focus shifts over time and parameters-satisfiers become dissatisfiers, delighters become satisfiers, etc.

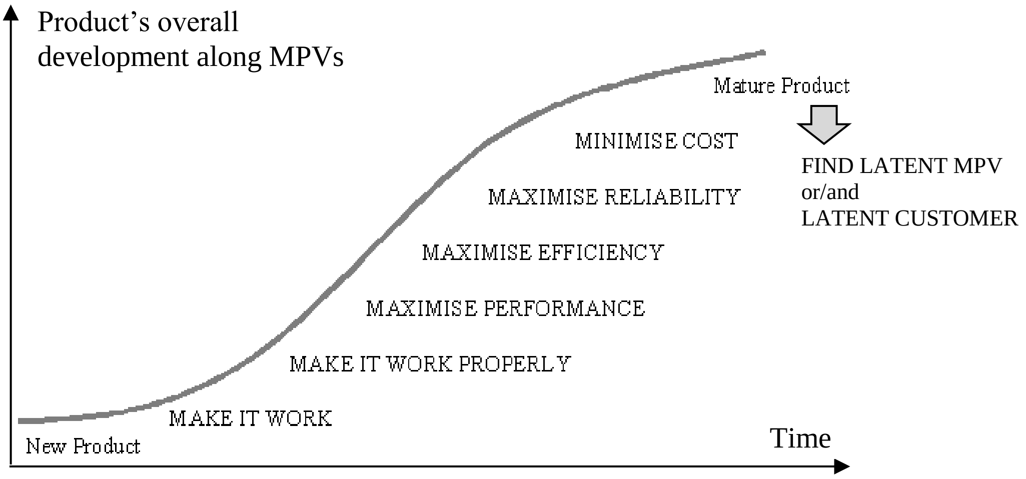


Fig. 3. Typical S-curve of the NPD focus [14]

3.2. Clarification of Step 6: Identifying the Correlation between Product and Customer MPV Profiles

The correlation between customer and product MPV profiles may be identified by calculating the rank correlation coefficient ρ using, e.g. formula (1) implemented in MS Excel's function CORREL(X,Y):

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \quad , \qquad (1)$$

where x_i and y_i are the customer and product rankings of i-th MPV respectively; $i = 1 \ldots n$, where n is the total number of selected MPV candidates; $\bar{x}$ and $\bar{y}$ are the customer and product average ranks across all MPVs.

The correlation coefficient ρ varies between 1 and -1 depending on the similarity of the customer's and product's MPV profiles. If ρ is close to 1, then the customer's and product's needs and wants are alike; if ρ is close to -1, then they are quite opposite.

Generally, if $\rho > 0$, then it makes sense to skip Step 7 (Table 1) and proceed further with NPD without looking for latent MPVs or latent customers.

3.3. Clarification of Step 7: If the Correlation Is Weak

If the rank correlation coefficient $\rho < 0$, then it is necessary to proceed with Step 7 (Table 1) in order to exercise some of the following opportunities:

- Identify and implement latent MPVs/features that make the product's MPV profile better match the VOC. Typically, latent MPVs are implemented by transferring to the product some useful functions/features that are currently delivered to the target customer via other products.

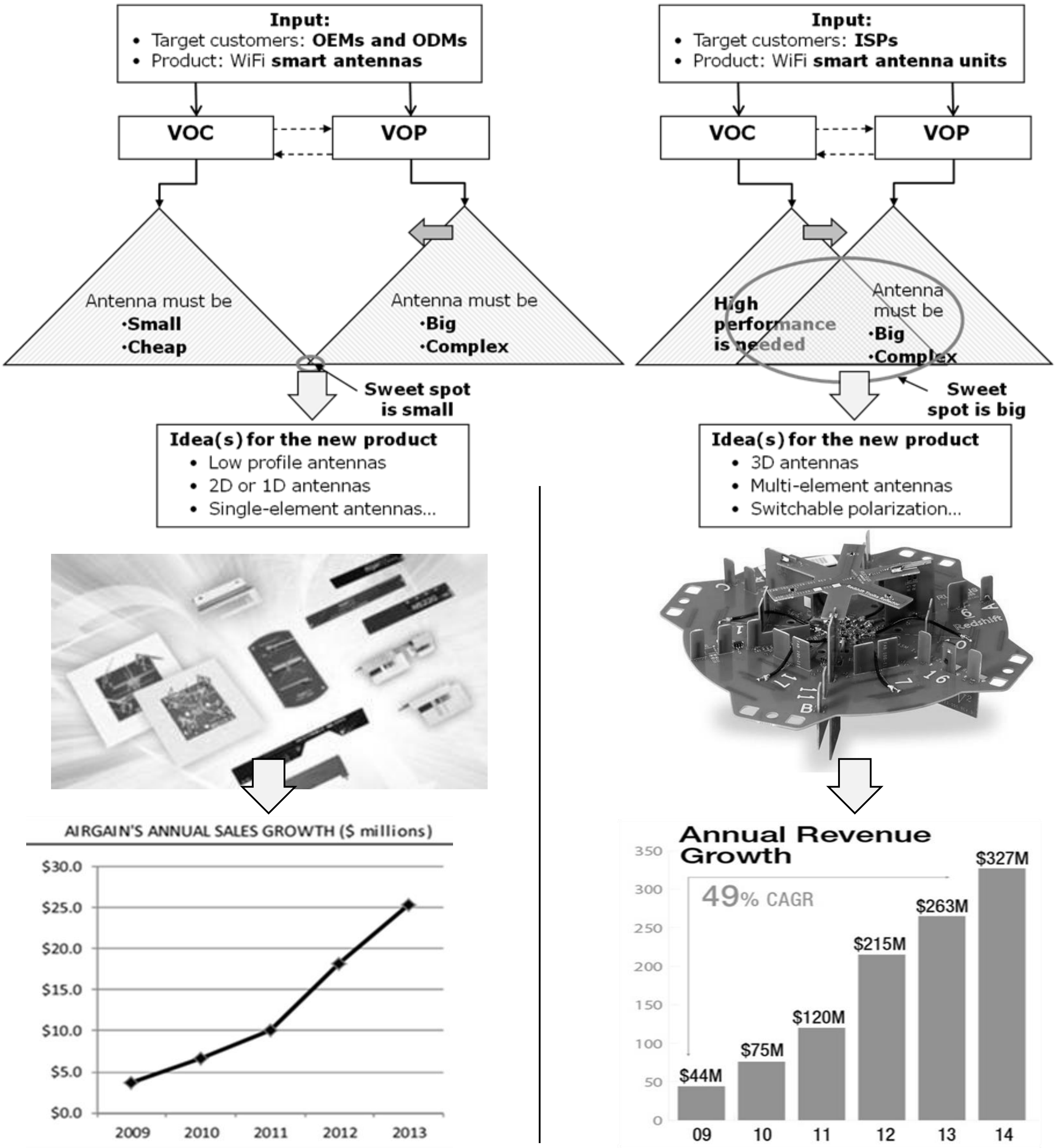
- Select another target product that better matches the VOC (i.e. the customer's MPV profile). This product can be chosen from among competing products that deliver the same functionality as the initially selected target product, but use a different action principle.
- Identify a latent customer that better matches the VOP. These customers may be found among those who interact with the target product but do not currently use its functionality. Typically, latent customers need some functionality of the product that the initially selected target customers do not.
- Select another target customer whose MPV profile better correlates with the VOP. Sometimes such customers may be found among those who use the target product not as a standalone item, but as a component of a higher-level system.

4. Brief Case Studies and Discussion

Case studies presented here are based on the author's experience in developing WiFi smart antennas (SAs) for Airgain Ltd., which have been partially described in other papers [12, 17].

4.1. WiFi Smart Antenna: the VOC and the VOP

Fig. 4 [17] illustrates how the match between the VOC and the VOP influences the business of two companies, Airgain, Ltd. and Ruckus Wireless, that develop and sell WiFi SAs.



a) Airgain situation **b) Ruckus situation**

Fig. 4. How a better match between the VOC and the VOP resulted in greater revenue [17]

As described in one of the papers [12], both companies started at about the same time and with the same idea of introducing a direction-agile antenna (SA) into WiFi units, with the aim of offering improved coverage, a higher data rate and more reliable connectivity.

The only difference between the two is how they focused their business: Airgain decided to sell its SAs to OEMs and ODMs as a component for WiFi units; Ruckus made the decision to produce its own SA-equipped WiFi units and sell them to Internet service providers (ISPs).

In both cases the product was at the beginning of its evolution, and, so, its VOP was focused on improving performance. The VOC, however, was quite different for these two companies:

• OEMs and ODMs required Airgain to deliver cheap and small antennas;

• ISPs wanted Ruckus to deliver units with high performance and reliability.

Detailed product and customer MPV profiles for both companies are given in Table 3, where the rank correlation is calculated using formula (1).

Table 3

Customer's and product's MPV profiles for Airgain and Ruckus

MPV	Rank (identified according to Table 2)		
	Product profile (SA's VOP)	Ruckus's customer profile (ISP VOC)	Airgain's customer profile (OEM/ODM VOC)
High performance (data rate)	3	3	2
Big coverage area	3	3	1
Sustainable connectivity	2	3	2
Small footprint of the antenna	2	0	2
Low profile (height) of the antenna	1	0	3
Low cost of the antenna	2	2	3
Rank correlation ρ between VOC and VOP:		**0.75**	**-0.76**

Table 3 shows that Ruckus's VOC does correlate with the VOP (ρ=0.75), while Airgain's VOC does not correlate much with the VOP (ρ= -0.76).

As seen from Fig. 4, both companies have sustainable business, but Ruckus generates over ten times higher revenue than Airgain because of a significantly better match between its VOC and VOP.

This just confirms the importance of providing a good match between VOC and VOP.

4.2. WiFi Smart Antenna: Latent MPVs and Latent Customers

As mentioned in section 3.1, identifying latent MPVs and/or latent customers becomes important once the product matures, while at early stages of the product's evolution there are more urgent tasks for the NPD.

This is illustrated by the following example from an SA development project.

At the beginning of the development in 2002, during the product-centric Function Analysis (Fig. 2b), the GEN3 team found that an antenna inherently performs the function "to sense changes in the environment" since any change in the environment immediately affects the signal strength received by the antenna.

For a WiFi antenna this is a harmful function because it disturbs connectivity; so, one of the goals of an SA was to eliminate this function - by dynamically adjusting the SA's directional pattern - to compensate for changes in the environment.

On the other hand, this function ("to sense changes in the environment") can be very useful in, for example, different kinds of motion sensors. In fact, this is the main function implemented in many intrusion- and fire detection systems.

Therefore, we proposed adding the functionality of home/office intrusion detection to SA-equipped WiFi units (see Fig. 5), which would only require including a piece of code in the existing software that steers the SA.

End users of such units would obtain a free home or office intrusion detection system without affecting the main functionality of a WiFi unit. This is a typical latent MPV.

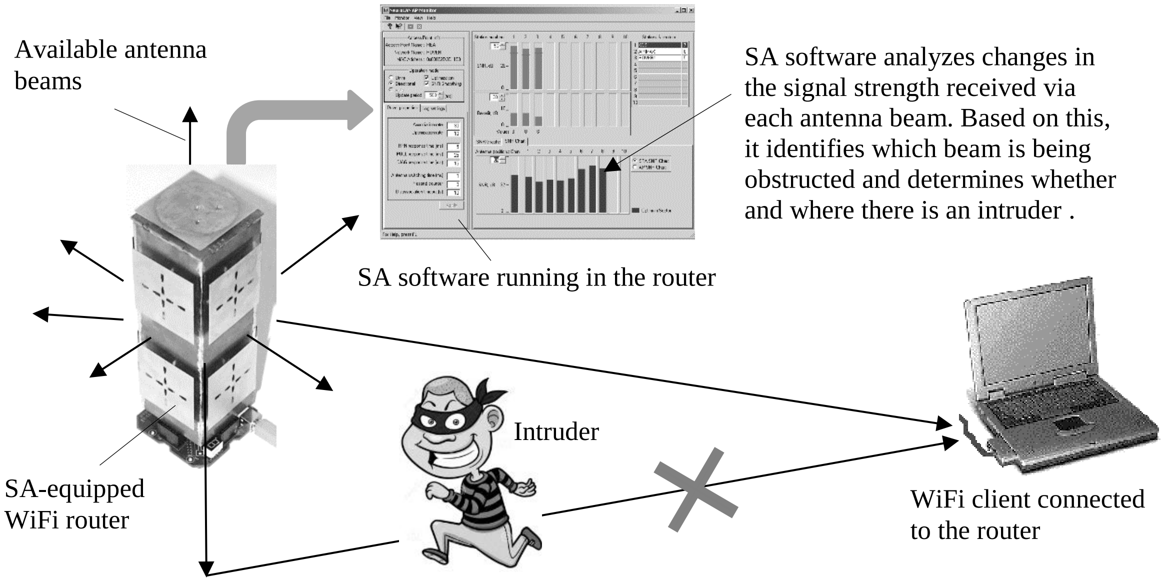


Fig. 5. WiFi intrusion detection system that GEN3 proposed in 2002

GEN3's client has rejected this idea and the intrusion detection system was not implemented.

Based on the approach presented in this paper, this was probably a wise decision because at that early stage in the SA's development such additional functionality was just a "delighter" for both the VOC and the VOP:

- End users were looking for wireless network connectivity and performance. They would unlikely rate a WiFi alarm system very highly.
- On the product side, the urgent tasks were to make the SA technology work properly and to improve its performance.

Therefore, implementing additional features in 2002 would most likely not have been successful.

Only in 2012-2013, when WiFi systems (including those using an SA) had become mature, did a group of MIT researchers reinvent this idea and conduct in-depth studies on the possibility of sensing objects using WiFi systems [18].

Soon after, this group came up with a health monitoring WiFi system. This system was capable of detecting subtle movements in the environment, even through a wall – such as the rise and fall of a person's chest [19]. This feature is useful for monitoring the breath and heartbeats of the elderly or people on life support when it is undesirable or impossible to attach any sensors to the person's body. It is also useful as a baby monitor.

Recently, the researchers made further progress and came up with a WiFi system that locates people and even recognizes their gestures through a wall [20]. Besides intrusion detection and obvious use in law enforcement or military, this system can be employed in a smart home environment, for example, to control different devices and appliances using gestures.

And now this technology is being commercialized for homecare givers by a newly founded startup company named Emerald (see http://www.emeraldforhome.com/).

In the context of this article, it is necessary to emphasize that

1. The above-described latent MPV (the ability to sense movements in the environment) serves latent customers (hospitals, assisted living homes, law enforcement groups, etc.) as discovered by the researchers. None of them were among the initially selected target customers.

2. This latent MPV was initially a harmful feature that the developers were trying to eliminate. However, for latent customers this is a critical feature (i.e. a dissatisfier as in Table 2), which is actually more important than the WiFi data performance that the target customers wanted in 2002.

4.3. Discussion

The case studies presented above confirm the usefulness of the algorithm for product-oriented MPV analysis proposed in this paper.

The algorithm was successfully tested in a few NPD projects, but it needs to be tested and refined further.

Also, more detailed recommendations for identifying latent MPVs and latent customers need to be developed. This, however, is a topic for another paper.

5. Conclusions

This paper suggests an extension to the existing algorithm for MPV analysis. The extension brings into consideration a product's true needs and wants and makes the current customer-oriented MPV analysis more holistic.

The novelty of the proposed approach is as follows:

1. Customer and product MPV profiles are introduced in order to characterize VOC and VOP numerically. These profiles reflect customer and product rankings of individual MPVs.

2. MPV's rank for the product is estimated depending on the product's current stage of evolution as identified through an S-curve analysis.

3. Recommendations on how to proceed with the NPD depend on the correlation between VOC and VOP. The correlation is easily calculated - using formula (1) above - from customer and product MPV profiles.

4. A product-centric Function Analysis is added to the customer-centric Function Analysis. This helps to identify "latent customers" and new "latent MPVs", which are not identified in the existing MPV analysis.

Further development of the proposed product-oriented MPV analysis may include:

• Refining/detailing the steps of the algorithm presented here.

• Developing detailed recommendations for identifying latent MPVs and latent customers.

Acknowledgements

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RESEARCH ON THE RANKING METHOD OF FAILURE SEVERITY OF COMPLEX MECHANICAL SYSTEMS

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Abstract

Failure analysis method can be used in the design stage of products and systems to predict and resolve the potential failures, which can greatly shorten the design cycle and improve the reliability of the product. In order to use the limited resources of solving problems on the failure of a relative the greater importance degree, it is necessary to rank all of the failure by the important degree.When analyst using traditional risk priority number (RPN) method on the large and complex mechanical system, there will appear many problems on the analysis of the weighting, repeatability, discrete, sensitivity and accuracy, which eventually cause the distortion of the ranking results of failures. Based on the study of the failure characteristics of the complex mechanical systems, the paper proposes a risk priority method based on economic loss: ELRPN method, which combines qualitative analysis and quantitative analysis. The method replace the severity and the degree of difficulty with the probability of failure and the economic losses caused by the failure of the traditional RPN method, which reduces the subjectivity in the calculation of the risk priority value, and making the analysis result more in line with the objective reality of the failure of the complicated mechanical system.

Key words：Failure analysis; RPN ; Severity ; Economic loss;
Category Number of Chinese Classification：1005-9830（2011）00-0000-00

0. Introduction

Failure analysis which used for system design and processing stage can predict the failure that may occur in the system and analysis its influence on the system and resolved in advance. It also can improve the reliability of the system. With the improvement of the complexity of modern systems, the number of potential failure after failure analysis is usually quite large. In order to concentrate limited human and material resources on the failure which is harmful to the system, analysts must sort according to the severity of the potential failure effects. In order to make the ranking result in line with the actual situation of the system, the researchers have made a lot of research on the method of failure sorting, and have put forward some effective methods. At present, the most widely used method on failure analysis field is the risk priority number (RPN) method which is one of the failure mode and effect analysis (FMEA) methods. In the face of complex systems, RPN method gradually showed its inherent limitations, and ultimately leads to the distortion of the results of the analysis.

In this paper, based on the engineering practice of mechanical system failure, the RPN method is improved, so that the analysis process is more objective, and a new method of failure ranking is put forward, which is based on the economic loss.

1. RPN Method and Its Defects

1.1 Introduction of RPN method

The RPN method is a standard tool for risk grade classification in FMEA. In the engineering analysis, once all the failure modes have been computing RPN, analysts will be in accordance with the RPN values exalted to low on the corresponding failure modes taking failure measures, to eliminate or reduce the main failure modes which showed high serious degree, occurrence rate and difficulty level[1] . After the implementation of the solution, the RPN value will be recalculated to determine whether the risk of failure has been reduced or the effect of solution measures [2].

In the FMEA method, the RPN value is the result of the multiplication of the risk parameters of the potential failure mode---Severity (S), occurrence rate (O), and the degree of difficulty (D)[3,4], which can be expressed as:

$$RPN = S \times O \times D$$

In the three risk parameters, S refers to the evaluating indicator. When the potential failure mode occurs, the severity of the impact on the following processes, subsystems, systems, or customers, are generally divided into 10 grades, disaster, deadly, critical, and mild and so on. Values range from 1 to 10. O refers to the possibility of emergence of a specific cause or mechanism of failure, are generally divided into 10 grades, disaster, deadly, critical, mild and so on. Values range from 1 to 10. D is the difficulty of discover the failure causes. It refers to the difficulty when it flow into the market and be discovered before lose efficacy. It's the index of ability to detect failure modes, causes and mechanisms, are generally divided into 10 grades, very difficult, difficult, possible,ability and so on. Values ranges from 1 to 10.

Generally speaking, in RPN analysis, the values of S,O,D are all determined by the expert analysis team, the greater the value of RPN , the greater the potential risk of system design. This RPN analysis method is simple to operate and easy to understand. It has been matured in engineering application, and has formed the standard. However, with the elevation of the complexity of the system being analyzed, the performance of RPN method is gradually being questioned by researchers in the application.

1.2 Defects of RPN method

With the improvement of the complexity of the system, system failure is showing multiple causes characters and due to the RPN method inherent defects. When the RPN method is applied to this kind of system, the analysis result often deviates from the actual system. That is the appearance of distortion.The defect of RPN method is mainly manifested in the following aspects:

(1) .Weight measurement of RPN value
Traditional calculation of RPN values are assuming the 3 parameters: S, O, and D. They have the same importance, thus neglecting the weights of the 3 parameter. Such as Patrick[5], who stressed the severity of S and the occurrence rate of O are two key factors, should be analysis first by FMEA , rather than giving equal weight to the Degree of difficulty D.

(2).The repeatability of RPN value
The 3 parameters S,O,D have 1000 kinds of combination, but their product has only 120 different numbers. So there is a lot of repetition [6]. The same RPN value corresponds to a variety of different combinations of the 3 parameters. These different combinations are not separated from the RPN analysis method.

(3). Discrete property of RPN value
In the traditional RPN analysis method, the value range of 3 parameters S, O, D is from 1 to 10, and then the calculated RPN value ranges from 1 to 1000. In fact, the RPN value is not continuous, but there are a lot of blank areas because of the unavailable numbers (for example, the number 11, 22, and 11, which is multiple of 11). The discontinuity of RPN value is difficult to explain the significance of the difference of RPN value.

(4).Sensitivity of RPN value
The sensitivity of RPN value is mainly manifested in the situation when one of the 3 parameters O, S, D has a small change. It may have a great impact on the final RPN value, the impact of a small change in a parameter can be amplified.

(5).The accuracy of RPN value
The calculation formula of RPN value is controversial. There is no principle to support the formula: Why it uses the product of these 3 parameters S,O,D to get the RPN value. And in the calculation formula of RPN value, only the 3 parameters of safety are considered, other important parameters are ignored. In addition, due to the S and D are using language descriptions, different levels of assessment may have a great impact on the final results of the RPN value.

(6) .The multiple causes of the complex system's failure
The failure of the complex systems often has many reasons. That is to say, the failure may be caused only by the occurrence of an initial event.It may also be caused by the two or more than two initial events (logical "and"). Perhaps any one of the two or more than two initial events may have caused the failure (logical "or"). Traditional RPN method does not distinguish between them, but directly evaluated by the experts to give the failure results a probability of occurrence O,which will also directly affect the authenticity of the analysis results.

2. Presentation of the ELRPN Method

Aiming at the defects of RPN method, a RPN method which is based on the economic losses---ELPRN method is proposed in this paper.The analysis process is shown in Figure 1.

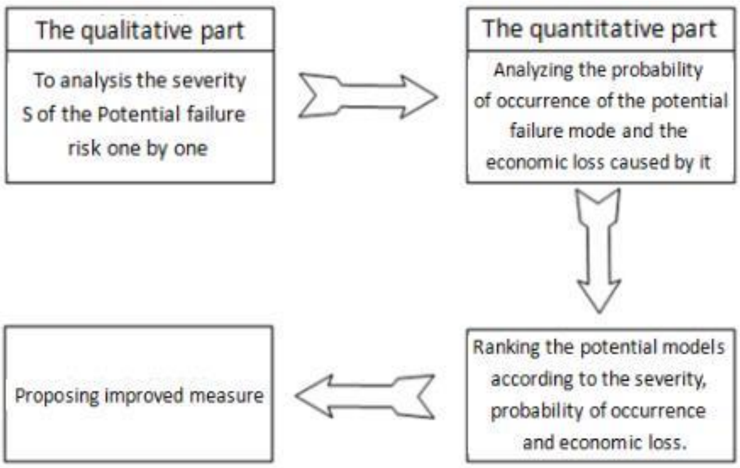

Fig.1 The process of ELRPN method analysis

The whole analysis process is divided into two parts qualitative and quantify with the ELRPN method. The severity S which cannot be quantitatively described is taken as a threshold value is used for analysing the degree of risk of the failure effect qualitatively. Failure mode is directly listed as an important failure mode and should be solved prior, which is greater than or equal to 9. For the failure mode is required further quantitative analysis, which is (less than or equal to) not more than 9. Quantitative analysis in ELRPN method mainly includes two aspects: the occurrence probability of the initial event that lead to occurrence of the failure mode and the failure modes resulting in economic losses, multiplying both get ELRPN as a failure severity ranking of reference value. Compared with the traditional RPN method, that using economic losses to measure the effects of failure modes on the product, personnel, or environment is not only easy to understand, but also more intuitive. On one hand, the economic losses caused by some failure modes can reflect the severity of the failure mode; on the other hand, the economic loss can also reflect the degree of difficulty of a failure mode at some extent.

The formula for quantitative analysis of ELRPN is:

$$ERPN(S_i) = P(S_i) \cdot E(S_i) \qquad (1)$$

Where: ELRPN (S_i) is the risk priority of failure mode S_i which based on economic loss; P (S_i) is the probability of failure mode Si, E (Si) is the economic losses caused by the failure.

2.1 Probability analysis of failure mode

For the multi-factors which lead to complicated system failure, the failure mode probability calculation of ELRPN is also divided into 3 kinds of situations:

(1) Individual initial events leading to failure

$$P(S_i) = P(C_1) \qquad (2)$$

Where: P (Si) is the probability of the occurrence of the failure mode, and P (C1) is the occurrence probability of the initial event that result in the failure mode.

(2) Two or more initial events are together contributing to the occurrence of faliure.

If the two or more initial events leading to the occurrence of a failure mode is logical "and"; the probability of the failure mode is the product of the probability of a few initial events:

$$P(S_i) = \prod_{j=1}^{n} P(C_j), \quad n \geq 2 \qquad (3)$$

Where, P (Si) is the the occurrence probability of failure, and P (Cj) is the occurrence probability of the first J event in N initial events.

(3) Any one of two or more initial events will result in failure.
If two or more initial events that cause a failure mode is the logical "or", the occurrence probability of the failure mode is:

$$P(S_i) = 1 - \prod_{j=1}^{n} \left(1 - P(C_j)\right), \quad n \geq 2 \qquad (4)$$

Where, P (Si) is the the occurrence probability of failure, and P (Cj) is the occurrence probability of the first J event in N initial events.

2.2 Economic loss analysis of failure mode

The ELRPN method considers that the economic losses caused by failure should include 3 parts: loss of output, breakdown maintenance cost, and the loss of raw materials for production caused by fault. That is:

$$E(S_i) = E_1(S_i) + E_2(S_i) + E_3(S_i) \quad (5)$$

Where, the E1 (Si) is the loss of output caused by failure mode Si, that is, the estimated total output value of the output because of the failure mode during the period of production stagnation; E2 (Si) is the failure mode Si resulted in the breakdown maintenance cost, namely, the maintenance expenditure which used to eliminate failure or to resume production; E3 (Si) is the loss of raw materials for production because of the production stagnation, which caused by failure mode S_i.

$$E_1(S_i) = e \times t \times W_P \quad (6)$$

Where, e is the production efficiency of the system analyzed; t is the time of production stagnation caused by failure; Wp is the output value of a single product produced by the system.

$$E_2(S_i) = W_M + W_L \quad (7)$$

Where,W_M is the required material, component(for repair and replacement of faulty components) costs, which is applied to eliminate or resume production. W_L is the labor costs.

$$E_3(S_i) = W_{PM} + W_{Others} \quad (8)$$

Where, the WPM is the loss of production material caused by the failure model (such as unqualified products of material loss) and the raw material loss during the stagnation of production(such as the volatilization of alcohol raw materials in the process of alcohol filling equipment maintenance). In addition, the other losses are W_{Other};

3. Application Model of ELRPN Method

Based on economic loss- the ELRPN method, the ranking method of failure level is proposed in this paper, which is divided into 7 steps. The application flow chart is shown in figure 2.

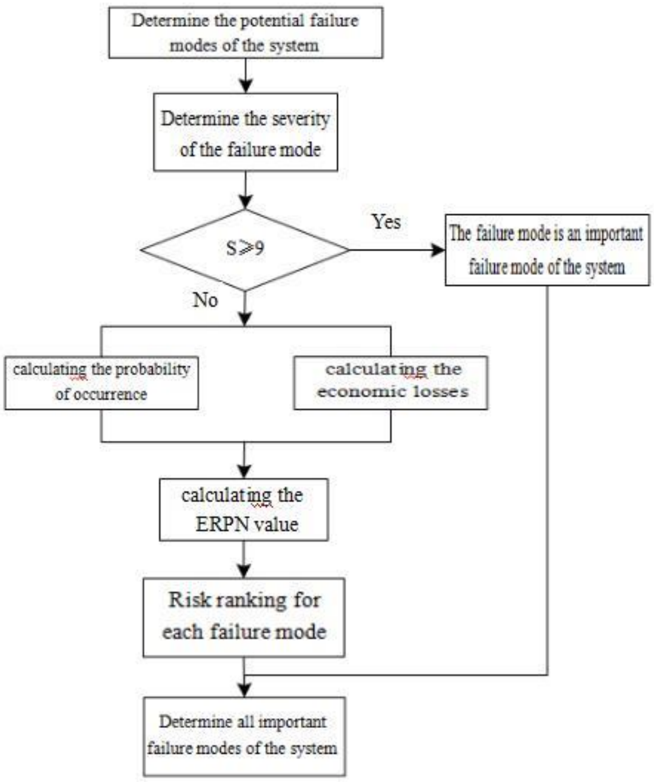

Fig. 2 The application process of ELRPN method

(1).Identify potential failure modes of the system.
(2).In view of the potential each failure mode of the system, the effects of the system, personnel and environment are analyzed, and the risk severity parameters of S are listed.
(3).For the failure mode which the severity S is 9 and 10, directly designates it as an important failure mode of the system and adopts the design or manufacturing, assembly of the solution.
(4).For the failure mode which the severity S is less than 9, at first, we analysed the number of the initial event and its failure mode logic relationship. Then according to the logical relationship between the probability of formula (2) ~ (4), we calculated every failure mode occurrence probability p (SI). At last, the economic losses caused by each failure mode are analyzed, and the E (Si) value of the system is calculated according to the formula 5~8.
(5).According to the probability of the each failure mode P (Si) and the economic losses caused by E (Si), the value of risk priority number ELRPN (Si) is calculated based on the risk of economic loss.
(6).Sort all the failure modes which severity is less than 9 to prioritize the risk according to the value of ELRPN (Si).
(7).Identify all important failure modes, including step 2.

4. Engineering Case

An automatic quantitative feeding device is shown in figure 3. Its function includes: taking out the aggregates in the bin according to the quantitative, throwing it into the mould, and scraping the spilled aggregates according to the design height.

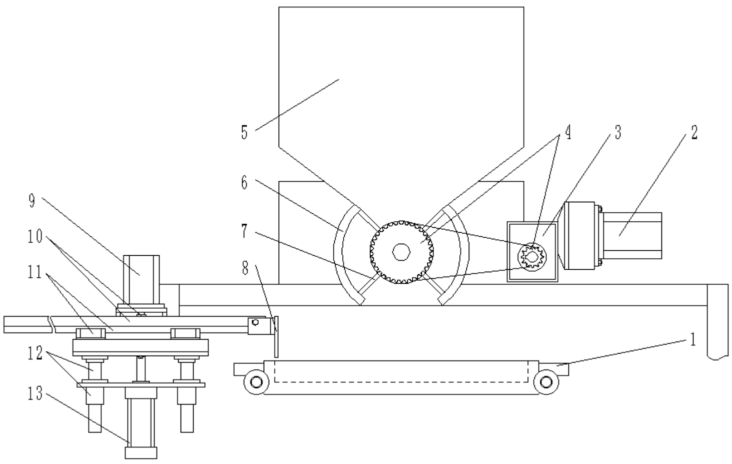

Fig. 3 Schematic diagram of automatic quantitative feeding device

1—mould; 2—stepper motor; 3—reducer; 4—chain drive group; 5—bin; 6—quantitative box; 7—rotary piece; 8—scraping plate; 9—stepper motor; 10—rack and pinion gear; 11—linear guide rail pair; 12—linear bearing pair; 13—lifting cylinder

Failure analysis is shown in Table 1 for the potential failure modes of the system. The process of ELRPN which is applied to the system failure sorting is as follows.

Table1

Potential failure mode of the automatic quantitative feeding device

feed device	steps	failure mode
one	Rotating pla te 7 rotating 90 degrees	①The error position of the rotating blade which is caused by the error accumulation of the stepping motor will make the granulesless than the design flow. □Due to the pressure of silo pellets of pellets, Water glass adhesion in raw materials or the static between pellets and the rotating piece, the aggregate adhesion on the rotating piece, the pellets throwing to the mold are less than the designed capacity.
two	Retraction of the cylinder rod of the lifting cylinder 13	□The straightness of cylinder rod 13 is not accurate; it will be stuck when draw back, could not reach the designed falling head, lead to the shaving height incorrect.
three	Rack 10 out	□Rack is stuck in the process of extending, and failes to reach the design trip, resulting in flat scraping. □Rack and pinion 10 cylinder rod is not straight, when the scraper rise or down, resulting in aggregate after sloping.
four	Rack 10 retract	□The rack is stuck when it retract, unfinished the twice scraping 。
five	Cylinder rod 13 extending out of the lift cylinder	⑦The cylinder 5 cylinder rod straightness, which will be stuck when extends, leading to the scraper failed to break away from the mold, and cash the scraper at moving.

(1). To analyze the risk severity of each failure mode

1) In the failure mode ① and ②, what the aggregate is less than the design flow of mould will lead to final design pressure plate density less than expectation. So the severity of failure patterns should be "significant" - product performance is reduced, and the comfort or persuade function may not be able to operate. Namely S1 = S2 = 6.
2) In failure mode ③, the clamping dead of the cylinder rod of the cylinder 13 can not reach to the design of the scraping height, eventually leading to mold pellets without being flattened, not smooth and forming. Therefore, the failure mode severity should be "extreme" -- the products can not operate due to lose its main function, neither the system is, namely S3=8.
3)In the failure mode ④, the gear and rack vice jammed will make scraping board can't complete the whole process, eventually led to the aggregates inside the mold is not calibrating and can't be successfully pressing to be formed. Therefore, the severity of failure mode four is also S4=8.
4)In the failure mode ⑤, the scraping board rose and drop will make the pressed board with non-uniform density. Therefore, the severity should be "significant"--the product performance is reduced, comfort or persuasive function may not be able to operate.That is S5=6.
5)In the failure mode ⑥, the scraping board stops in the process of retracting, eventually leading to the aggregates inside the mold is not calibrating and leading to aggregates can't be formed when the plate is pressed. Thus, the severity is "extreme"--the product and the system can't be operate because of the main function has lost. That is S6=8.
6)In the failure mode ⑦,the scraping board failed to separate from the mold in accordance with the design movement, eventually leading to damaged the scraping board, even the whole

device, and it also threatens the operators. Therefore, the severity is “dangerous”--failure is dangerous and there is no warning. Failure made the system operate paused, or involved with the government regulations which are not conform to the behavior. That is S7=10. According to the above analysis, the seven failure modes of the automatic quantitative feeding device can be obtained, as shown in table 2.The severity of failure mode ⑦is S7=10 > 9, so it can be ranked important failure mode.The severity of the other six failure modes are less than nine, which need to enter the analyze of the next step.

(2).Calculate the ELRPN value of each failure mode based on the economic loss

For each failure mode, analyze the influence of the logic relation and failure of the initial event, calculate the value of P (Si) and E (Si), and finally the ELRPN (Si) value of the failure mode is obtained. As shown in table 2.

Table2

The severity S of the 7 failure modes of automatic quantitative feeding device

failure mode	①	②	③	④	⑤	⑥	⑦
Severity Si	6	6	8	8	6	8	10

(3). According to the value of ELRPN, sorting and determining the critical failure modes which need to be taken corrective measures.

The 7 failure modes of automatic quantitative feeding device based on the priority of the risk of economic loss are shown in table 3.

Table3

Calculation of ELRPN (Si) value of the failure mode of automatic quantitative feeding device

failure mode	probability calculation		E(Si)				ELRPN (Si)
	explain	P(Si)	explain	E1(Si)	E2(Si)	E3(Si)	
1	An initial event, formula (2)	0.05	Induced density of a plate is less than the standard value, the product is available; Add feedback to correct; the system will not stop;	0	345	0	17.25
2	The 3 initial event is the logical "or", formula (4)	0.417	Induced density of a plate is less than the standard value, the product is available; The vibration bin and a non stick coating to correct; The system will not stop;	0	650	0	271.05
3	An initial event, formula (2)	0.0005	The pressing plate can not be formed, the product is not available; Replacing component to correct; The system needs to park and overhaul.	2160	204.5	100	1.232
4	An initial event,	0.0025	The pressing plate can not be formed, the product is not	3550	110	150	9.525

	formula (2)		available; Modifing gear pair to correct; The system needs to park and overhaul.				
5	An initial event, formula (2)	0.0005	Induced density of a plate is less than the standard value, the product is available; Adjust the assembly to correct; The system will not stop;	0	30	0	0.015
6	An initial event, formula (2)	0.0025	The pressing plate can not be formed, the product is not available; Modifing gear pair to correct; The system needs to park and overhaul.	3550	110	150	9.525

According to the results in Table 4, there are 3 important failure modes which need to be taken in the automatic quantitative feeding device, respectively: failure mode ⑦, failure mode ② and failure mode ①.

5. Conclusion

From the point of failure analysis of mechanical system, and on the foundation of studying the failure characteristics of mechanical system, the paper proposes a method of risk priority based on economic loss---ELRPN method, which combines qualitative analysis and quantitative analysis. The method replace the severity and the degree of difficulty with the probability of failure and the economic losses caused by the failure of the traditional RPN method, which reduces the subjectivity in the calculation of the risk priority value, and more intuitive for analysts.

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S-CURVE ANALYSIS ON MASS PRODUCTION TIMING USING TRIZ

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Abstract

As current technology becomes more competitive and complicated, it is important to forecast not only each stage of a technical product, but also the likely moment when a competing product may begin mass production. If you forecast the exact mass production timing in your industry, you can dominate its market in advance by completing your R&D activities quickly and by starting mass production earlier than your competitors. This paper develops the Two-Peak Curve Model from the second stage of S-curve development to predict mass production of a technical product two years after the second peak point of the number of patents. The model is supported by several examples, including a cross-point memory semiconductor product, a FinFET logic semiconductor product, and a virtual reality headset product.

Keywords: S-curve analysis, Two-Peak curve model, Mass production timing

1. Introduction

The S-curve model as a lifecycle of an engineering system is a well-known model of evolutionary development in several academic fields. The S-curve model shows a specific position among the whole technological evolution of an engineering system with its Main Parameter of Value (MPV) or ideality. The S-curve coincides with the invention evolution curve with the number of patents, as shown in Fig. 1. The entire S-curve includes many short-term S-curves within each evolutionary stage of an engineering system.

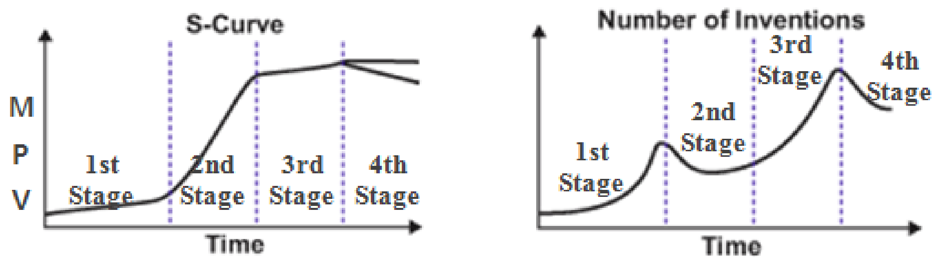

Fig. 1. General S-curve Model of Engineering System

The engineering system enters the market during the 2nd stage. The MPV of the engineering system increases rapidly through the 3rd stage. The 4th stage maintains a mature system on the market to jumpstart a new S-curve evolution stage or to finish the entire evolution.

TRIZ specialists and other researchers use the S-curve model to innovate their own engineering systems by confirming their positions. However, as current technology becomes more competitive and complicated, forecasting the exact timing of mass production of a competitive product is more important than determining each stage. If a company can predict mass production of a technical product in its industry, the company can dominate the whole market earlier than its competitors.

Thus, this study aims to predict mass production timing using S-curve analysis as a TRIZ tool as shown in Fig. 2. The paper introduces a new model, the Two-Peak Curve Model, to predict and describe the timing of mass production in the 2nd stage with the number of patents.

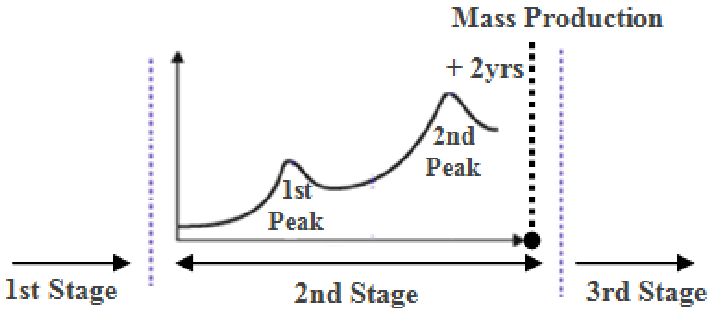

Fig. 2. Two-Peak Curve Model of Mass Production Timing

2. Materials/Methods

f[4]), it is a good industry to demonstrate these principles. There are many companies seeking to take a larger market share by launching new, innovative semiconductor products before their competitors. Two of these products [the cross-point phase-change random access memory (PRAM) and the fin-shaped field effect transistor (FinFET)] are used to verify the Two-Peak Curve Model hypothesis. We also examine a virtual reality headset, since this is an emerging market in the smartphone, game, and movie industry.

Table 1. Data Gathering Method

Product	**Cross-point Memory Semiconductor**	**FinFET Logic Semiconductor**	**Virtual Reality Headset**
Target Company	MICRON (USA)	TSMC (Taiwan)	SONY (Japan)
Data Gathering	Target filtering after keyword searcing		
Keywords	Cross-point, PRAM, 3D, etc	FinFET, Fin, Logic, etc	VR, virtual reality, etc
Number of Patents [1, 2]	558 patents	1594 patents	641 patents

[4] *Moore's law: the number of transistors in a dense integrated circuit doubles about every two years*

3. Results

3.1 Two-Peak Curve Model as TRIZ tool

S-Curve analysis is based on the trend of S-Curve evolution, which determines where an engineering system is in its development and what steps should be taken to improve it [3]. Thus, S-Curve analysis can formulate the most promising strategies for future development of a technical product.

An engineering system or technical product usually moves into mass production in the 2nd stage of general S-Curve analysis. Patents to reduce cost and minimize disadvantages are often applied for at this time. These pungencies in the 2nd stage must make two-peak trend on a number of patents in the Two-Peak Curve Model. Mass production can reasonably be expected to begin two years after the 2nd peak.

In the Two-Peak Curve Model, process-oriented changes are frequently patented in the 1st peak, and circuit-oriented patents increase in the 2nd peak. First, essential process improvements to the technical product are finished. Then, a detailed circuit/layout of improvement is implemented to launch the project into mass production with low costs and fewer disadvantages.

After the related patents are adapted to the technical product, mass production should begin within two years. Like the S-curve analysis, the Two-Peak Curve Model enables companies to dominate their markets by guiding strategies for future development of a technical product. The modern TRIZ using the Two-Peak Curve Model focuses not only on improvements to the technical product, but also on beating competitors to the marketplace [4].

4. Examples of the Model

4.1 FinFET Logic Semiconductor Product

The conventional structure of the logic MOSFET[5] semiconductor has several issues inhibiting the creation of smaller chip sizes. Thus, many companies in the logic semiconductor industry are trying to develop an innovative structure to overcome these limitations. One candidate, a FinFET product, has been in mass production since late 2014.

In 2015, the Taiwan Semiconductor Manufacturing Company (TSMC) began to produce the FinFET logic semiconductor product for its foundry customers, who need a small chip size for logic application processors [5]. Fig.4 represents the number of patents of the FinFET product applied for to the United States Patent and Trademark Office (USPTO) by TSMC. Through the Two-Peak Curve Model, the 2nd peak in 2013 accurately predicts that TSMC would mass produce the product in 2015.

[5] *MOSFET: Metal Oxide Silicon Filed Effect Transistor*

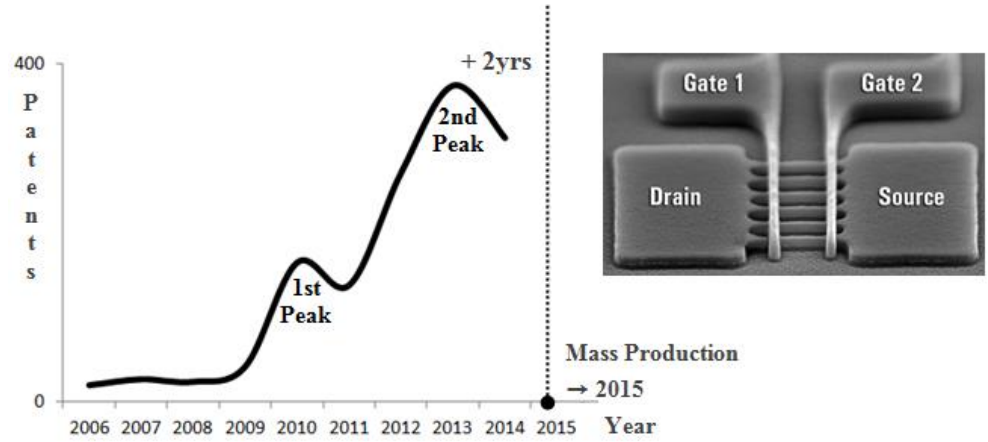

Fig. 4. FinFET Logic Semiconductor Two-Peak Curve

4.2 Cross-Point PRAM Semiconductor Product

DRAM and NAND have shrinkage limits and a high net cost per production, so several major memory semiconductor companies have been investing in research and development as they look for innovative products to overcome these problems. The 3D cross-point PRAM memory device is a strong candidate to replace current memory devices due to its chip efficiency and high performance quality.

Fig. 5 represents the number of patents related to the 3D cross-point PRAM semiconductor product that Micron, the leading company in the memory semiconductor industry, applied for from the USPTO. The 2nd peak occurred in 2013; thus, the Two-Peak Model predicts that Micron will produce the 3D cross-point PRAM semiconductor product in 2015. In mid-2015, Micron accordingly announced that they had finished developing it and it would be ready for mass production in late 2015 or early 2016 [6].

This case also strongly supports the Two-Peak Curve Model in the semiconductor industry. Other companies could have predicted the mass production time using the Two-Peak Model, and planned their research and development accordingly to dominate the market. The Two-Peak Curve Model would give these competitive companies a chance to take market share of a new memory product.

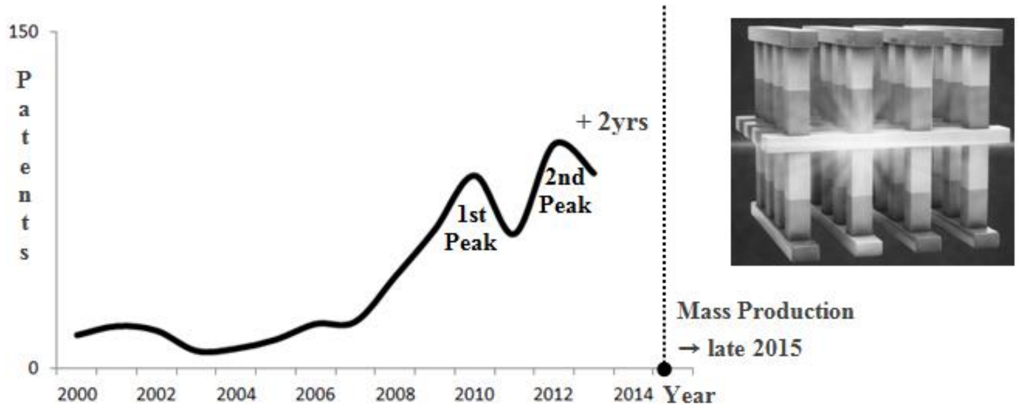

Fig. 5. 3D Cross-Point PRAM Semiconductor Two-Peak Curve

4.3 Virtual Reality Headset Product

In the near future, virtual reality will be one of the most important technologies in the game and smartphone industries. Many companies are trying to create a virtual reality headset product for use in games or smartphones. The Two-Peak Curve Model can be used to predict mass production timing for these products.

Fig. 6 represents the number of virtual reality headset patents applied for by SONY, a leading player in the game industry. After the first set of several peaks, there is a higher peak in 2014. This indicates that SONY would produce a virtual reality headset product two years later, in 2016. In early 2016, SONY began to mass produce a VR headset for sale with the PlayStation 4. This is an instance demonstrating the effectiveness of the Two-Peak Curve Model outside of the semiconductor industry.

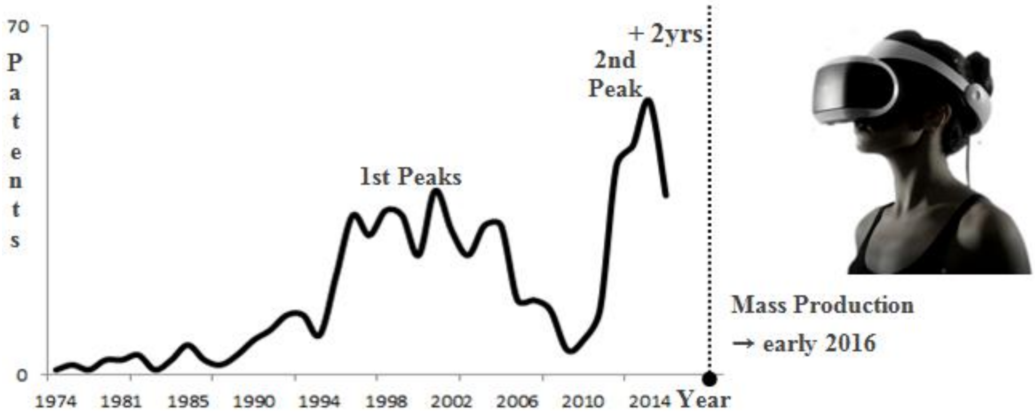

Fig. 6. Virtual Reality Headset Two-Peak Curve

5. Conclusion

The Two-Peak Curve Model is hypothetical, and may not predict mass production timing of many technical products exactly. There may be some industries which are less likely to follow this model.

However, the model is based on a powerful TRIZ tool (the conventional S-curve evolution model), and several examples show that the model could be a useful TRIZ tool to analyze the status of a technical product, especially mass production timing in the short-term 2nd stage. In today’s competitive market, the Two-Peak Curve Model could also steer research and development so companies could dominate the market in advance.

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SOLVING THE TONER ADHESION PROBLEM TO CYCLONE IN TONER MANUFACTURING PLANT

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Abstract

In this study, TRIZ was used for solving the toner adhesion problem to cyclone in toner manufacturing plant. In the drying process during manufacturing polymer-toner, the cyclone blocking problem caused by cyclone attached toner was endemic trouble. The toner attached to the cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (Bridge phenomena) and loss of the final production toner. According to the TRIZ problem analysis of RCA, function analysis, contradiction analysis, resource analysis and su-field modeling, it can be decided the direction of problem solving solution and can find concrete and simple practical solutions through heterogeneous field of technical analysis. Through the proposed solutions, it could be improved superior production efficiency minimizing changes of existing facilities. By TRIZ method that is simplifying the problem and searching solution in various fields, substantive solutions can be received within a few weeks starting project.

Keywords: TRIZ, cyclone blocking, production efficiency

1. Introduction

In digital era, we are facing severe competition and rapid change, and it is believed that prior occupation of core technologies is a key for surviving in business fields under these circumstances. The company without core technologies cannot lead the world and the bright future cannot be guaranteed in 21 century. Thus TRIZ can be a good methodology for the companies that need effective approach for innovation and invention.

Since TRIZ was introduced to Samsung Electronics in 1998, TRIZ methodology has contributed to various fields of Samsung products and manufacturing processes including mobile phones, semiconductors and home appliances (televisions, refrigerators, air-conditioners, printer, etc.)

This paper shows the application related to the toner manufacturing plant. Polymerized toner is made by complex chemical process.

In the drying process, the cyclone blocking problem caused by attached toner was endemic trouble. This problem brought about the loss of final production toner.

In this paper, the practical application of TRIZ for raising production efficiency is described.

2. Initial Situation and Problem Statement

The polymerized toner is produced by adding a plurality of external additive for the printing properties to a fine particle diameter of 6 ~ 7 ㎛ The polymerized toner is preferred in the market because of excellent printing quality, high printing speed, eco-friendly characteristics compared to pulverized toner. But manufacturing process of polymerized toner is complicated and the manufacturing costs is higher than the pulverized toner.

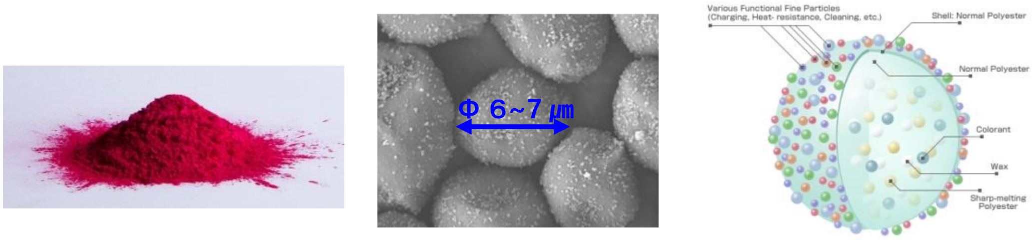


Fig. 1. Structure of toner

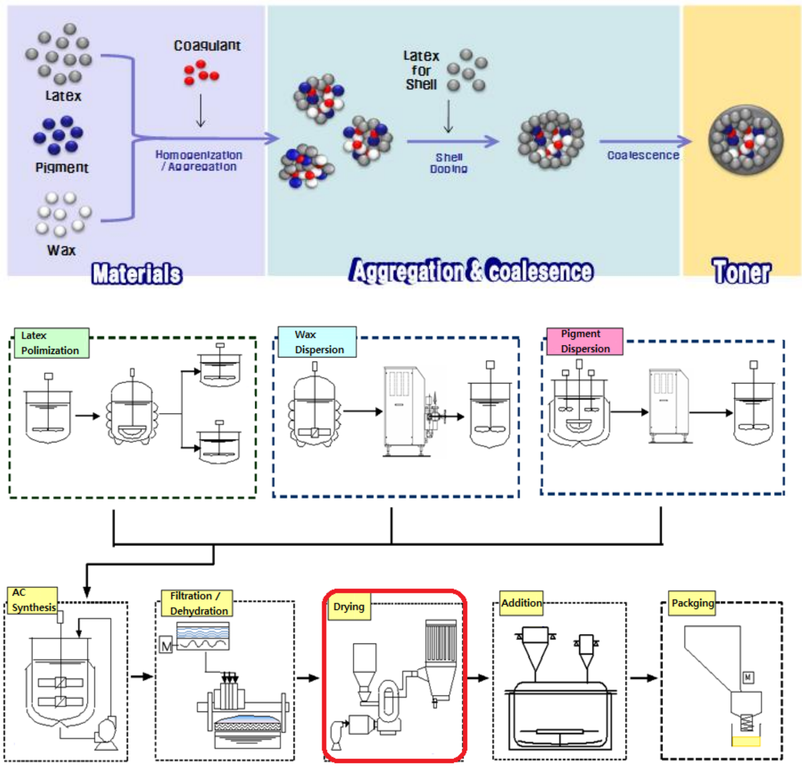


Fig. 2. The manufacturing process of the toner

The final step in the toner production process is a drying step. The toner having moisture is dried by hot air and the dried toner is collected by a centrifugal separator. The centrifugal separator is cyclone. Cyclone is a device which directly separates the particles using the centrifugal force. The inlet air flows into the cyclone is rotated spirally inside the conical cylinder. The toner particles are separated from the air in the cylinder inner wall by centrifugal force, they flow down toward the bottom wall surface, and they are stored in the dust reservoir (tank). Since the conical central portion is maintained at a negative pressure, the air separated from the toner particles rises to the top of the apparatus and it is discharged. In this case, the problem that the toner is adhered to the pipe & cyclone surface occurs frequently. (This is ‘fouling phenomena’.) The toner attached to the pipe & cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (this is bridge phenomena) and loss of the final production toner. Fouling phenomena have variations depending on seasonal characteristics, it occurs more frequently in high humidity on summer. In order to shake off the toner attached to the pipe & cyclone, electrical hammer was installed but the removing effect was so small and hammer caused a loud noise in the process. Through TRIZ, it was to improve the Fouling phenomena fundamentally, there was a requirement to minimize the modification of the current production equipment.

Fig. 3. Jet dry & pipe

Fig. 4. Cyclone for separation Toner

- **Centrifugal force:**

  $F=mr\omega^2= m(r\omega)^2/r$

  . ω : Angular speed

  . rω : Circular motion speed of object

  . Because $\mathbf{r_a > r_b}$, then $\mathbf{r_a\omega > r_b\omega}$

  And $\mathbf{F_a > F_b}$.

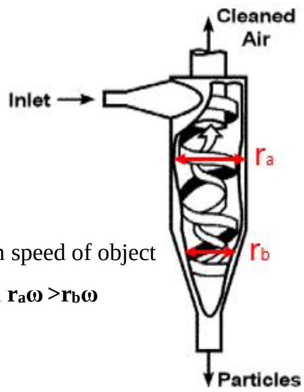
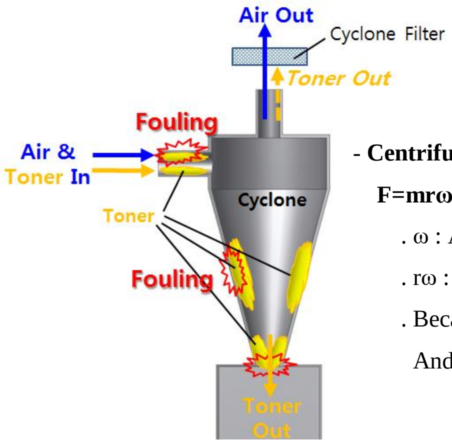


Fig. 5. The principle of Cyclone



- **Centrifugal force :**

  $F=mr\omega^2= m(r\omega)^2/r$

  . ω : Angular speed

  . rω : Circular motion speed of object

  . Because $\mathbf{r_a > r_b}$, then $\mathbf{r_a\omega > r_b\omega}$

  And $\mathbf{F_a > F_b}$.

Fig. 6. Fouling phenomena in Cyclone

3. Approaches to Solve the Problem

3.1. Definition of the problem

The goal of this project was to solve toner adhesion problem to pipe & cyclone in the drying process.

3.2. Root Cause Analysis

RCA was conducted to find out the primary cause of phenomena that toner attached to the inside pipe & cyclone and how to prevent the Fouling problems.

To reduce toner adhesion problem, simple solutions were derived. They are smooth surface processing of pipe, Teflon or hydrophilic property inner coating.

The pipe & cyclone insulation solution has been derived to reduce the temperature difference between inside and outside of the pipe.

In the drying process, the outside air is introduced in order to generate the hot air.

At this time, it was the underlying the solutions for removing moisture from the outside air that flows.

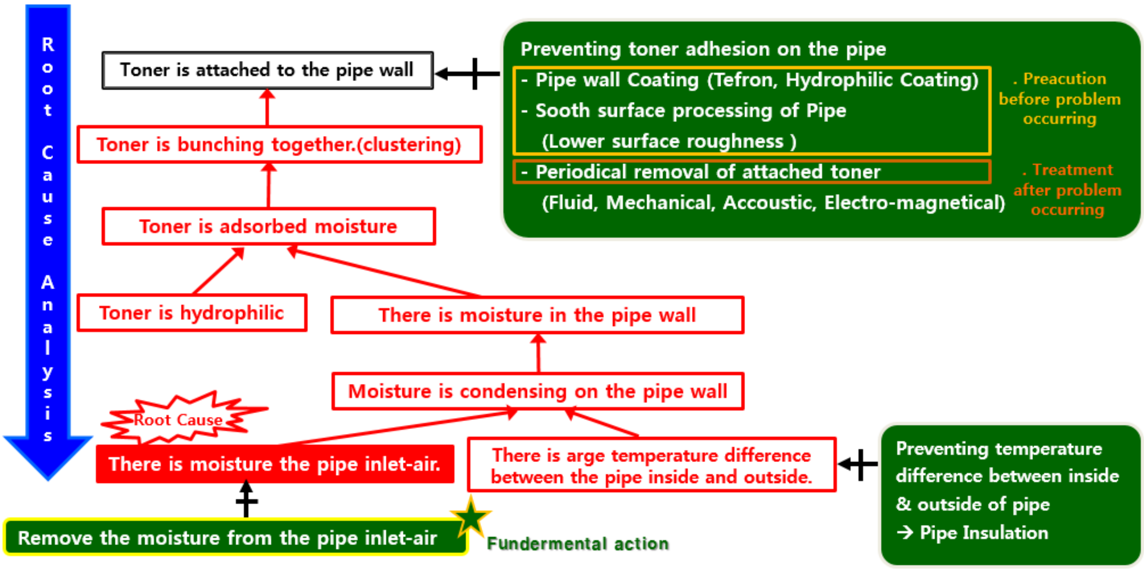


Fig. 7. Root Cause Analysis

Solutions for removing moisture of the external air flowing in the drying process was the general method used for milling, sugar, confectionery plant for preventing pipe clogging.

By RCA, it could be decided the direction of problem solving, heterogeneous field of patents and examples could get a concrete solution. Applications in other industries were a major basis to persuade process-engineer for concept implementation. That was useful to overcome the psychological inertia of a long period of time.

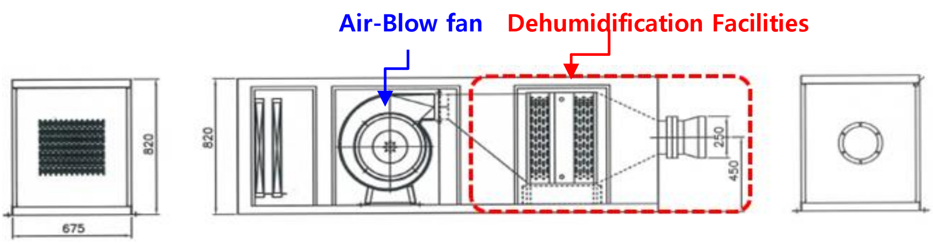


Fig. 8. Air-Blow Fan dehumidification facilities

3.3. Function Analysis & Contradiction Analysis

Functions were analyzed in cyclone system. There were useful function and harmful function between cyclone and toner at the same time. That was a point where the contradictory relationship occurs. Contradictions analysis was performed in order to derive a method for the periodic removal of the toner attached to a cyclone.

The end of the cyclone (neck point) gave the greatest effect on the dust separation performance of cyclone, and a main blockage occurred in the neck.

The technical contradiction was derived from this problem. If the diameter of neck(Φ)is large, then flow is not blocked but toner separation efficiency is low. And if the diameter of neck(Φ)is small, then toner separation efficiency is high but flow is easy to be blocked.

To solve the technical contradiction, 39 technical parameters were defined and 40 inventive principles were utilized by contradiction matrix.

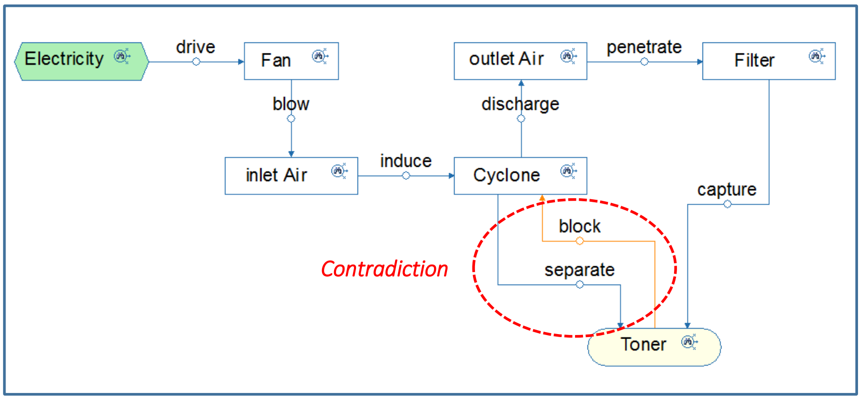


Fig. 9. Function Analysis

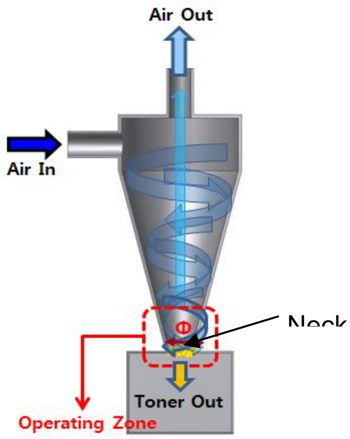


Fig. 10. Neck of Cyclone

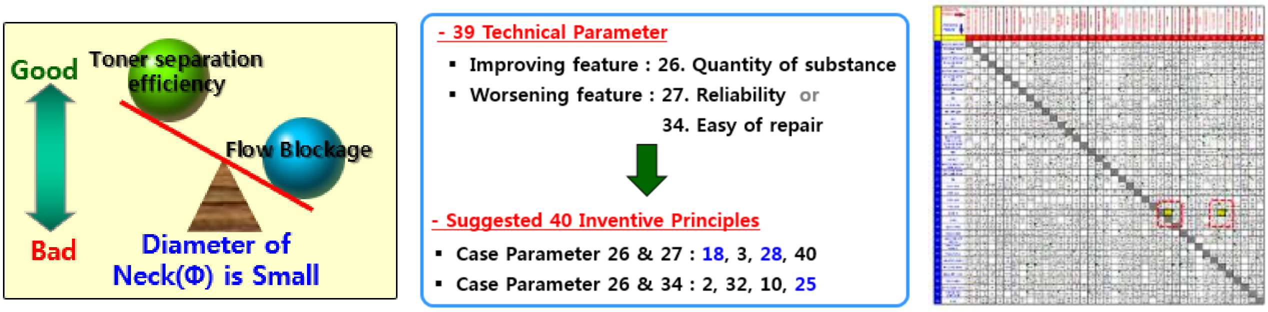
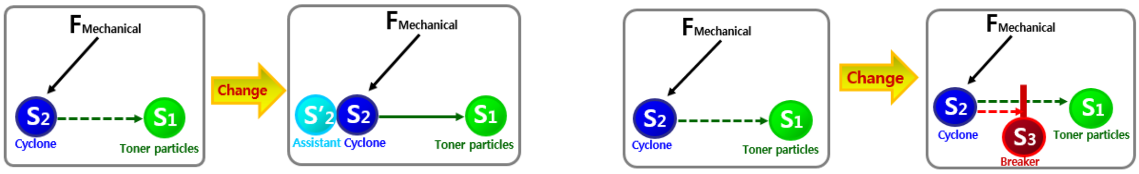


Fig. 11. Technical contradiction and Applying Inventive principles

The direction of improvement was taken by inventive principles No.18 (Mechanical vibration) & No.25 (Self-service) and more specific solutions were being found.

Proceeding of resource analysis in current technical system described the resources that could be utilized in the cyclone. Air flow in cyclone could be used for energy resource realizing mechanical vibration & self-service concept.

Su-Field Model and Standard-Solutions help to reify concept direction.



Standard solution 1-1-3 Standard solution 1-2-1

Fig. 12. Su-Field Model & Standard solutions

Position \ Property	Ready resource	Hidden & Derived resource
Inner system	- Tool : Cyclone	Shape of cyclone
	- Object : Toner	Toner additive
	- Field : Mechanical Field	
Upper system	Air	Air velocity, Centrifugal force, Turbulence, Tornado, Ascending current
Environment system	Moisture, Temperature	Condensation

Fig. 13. Resources Analysis

3.4 New Concept Solution

Function analysis, contradiction analysis, inventive principles, su-field model, resources analysis were used for laying down the solution direction in cyclone. And specific solutions were visualized by FOS in different-similar industries.

Finally, two solutions were materialized. They are vibrating flexible cone concept and self-vibration bar concept. A detailed description of the concept is shown in the figure below. The proposed solutions could be applied to cyclone vacuum cleaner, similar solution was realized.

This meant that its performance is proven effective in the field and market.

This fact could be logical and convincing evidence enough for the applying concept to the huge and expensive chemical plant.

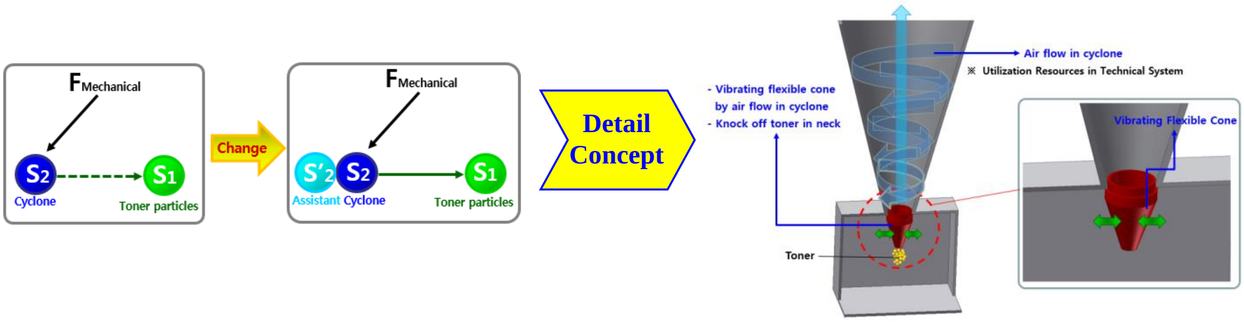


Fig. 14. Vibrating flexible cone Concept

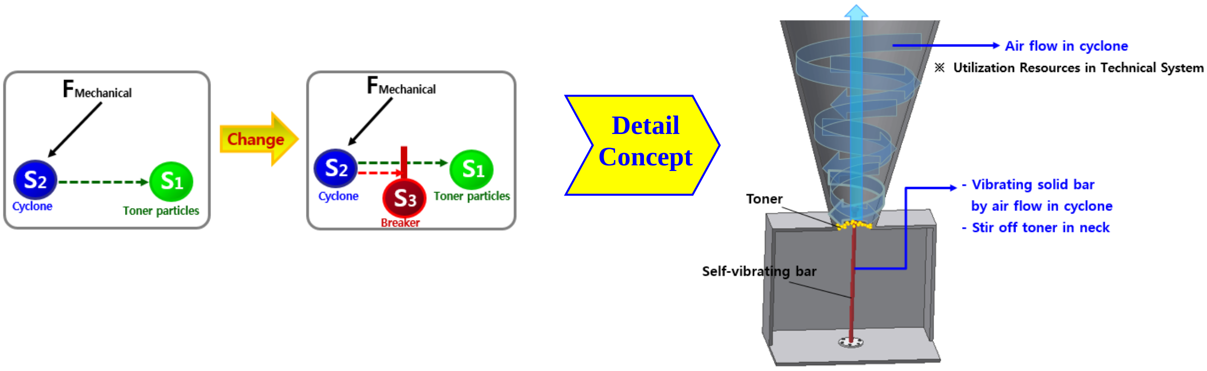


Fig. 15. Self-vibration bar Concept

Fig. 16. Self-vibration bar concept proto in vacuum machine

3.5 Implementation of Solutions. Final Results

Solutions to prevent toner adhesion and to remove toner in cyclone were drawn up by TRIZ.

The solutions are summarized as follows.

- Glary surface processing of pipe or Teflon or hydrophilic property coating
- Pipe & cyclone insulation for preventing temperature difference
- Removing moisture from the outside air
- Vibrating flexible cone concept
- Self-vibration bar concept

In particular, self-vibration bar concept design was made possible by minimizing the equipment changes and took effect immediately.

The results of applying the proposed concepts in the field went up to the production efficiency significantly.

4. Conclusions

This paper shows the TRIZ application related to toner manufacturing plant. In the drying process during manufacturing polymer-toner, the cyclone blocking problem caused by cyclone attached toner was endemic trouble.

The toner attached to the cyclone lead to the pipe pressure drop, cyclone jams, toner separation efficiency decreases, flowing backward symptoms (bridge phenomena) and loss of the final production toner.

According to the TRIZ problem analysis of RCA, function analysis, contradiction analysis, resource analysis and su-field modeling, it can be decided the direction of problem solving solution and can find concrete and simple practical solutions through heterogeneous field of technical analysis.

Through the proposed solutions, it could be improved superior production efficiency minimizing changes of existing facilities.

By TRIZ method that is simplifying the problem and searching solution in various field, substantive solutions can be received within a few weeks starting project.

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STUDY OF INTEGRATION PROCESS MODEL BETWEEN DESIGN-CENTRIC COMPLEXITY THEORY AND TRIZ

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Abstract

The establishment and analysis of the Su-Field model is one of the effective methods to find out the core problems of the system and reduces the system complexity by integrating the design process complexity theory (DCC) and Su-Field model in TRIZ. The complexity problems in the system are identified according to the definition and classification of complexity theory in DCC, the process model is established by integrating the design process complexity theory and Su-Field model in TRIZ and then verified by an engineering example.

Key Words: Su-Field model; DCC; TRIZ； Complexity

Introduction

TRIZ theory was invented by the Soviet union experts G. S. Altshuller and others, a complete system of invention problem solving theory was put forward on the basis of a large number of high level patent around the world.[1] after years of development and application, the analysis method of Su-Field has become the effective method to solve the problem of product invention, technical problems and identify the core problem for the system. The found basis of Su-Field model is the function of the system; the designing system can be represented by graphs. Complexity theory mainly studies the complexity produced in the process of product designing system, is the latest research achievements of complexity science and designing theory. The theory analyzes the complexity of the system from the perspective of the functional domain. In this paper, the system is decomposed to the typical components from the function analysis and find out the problems existing in the system. According to the definition and classification of complexity in DCC theory, the system problems are described by the complexity of corresponding design process; then converted to Su-Field model in TRIZ for decreasing the system complexity, in the end the process model is set up by integrating the design process complexity theory and Su-Field model in TRIZ.

1. The definition and classification of Complexity in DCC

The complexity concept in axiomatic design theory is defined as a measure of uncertainty in achieving a desired set of functional requirements [4]. It's a function, as shown in Fig 1.

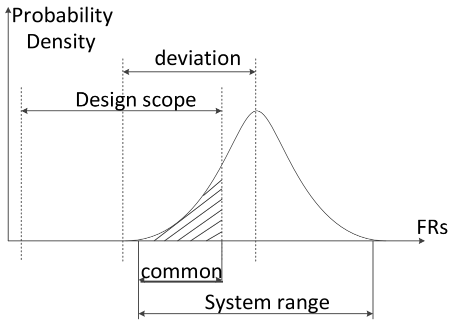


Fig 1 schematic diagram of the design scope and system range

There are four different types of complexity: time-dependent combinatorial complexity, time-dependent periodic complexity, time-independent real complexity and time-independent imaginary complexity [4].

Time-dependent combinatorial complexity is that system combination number is increasing gradually overtime, and complexity increases. The system appears harmful functions. The complexity grows over time, and is harm to the system. Time-dependent periodic complexity is a finite number of combinations. The system complexity increases first and then disappears.

This won't change over time, therefore under control.

Time-independent really complexity is that the system range is not fully in the design scope, namely the area of the shaded part is uncertain in figure 1.1[5]. It is real and does not change with time. Time-independent imaginary complexity isn’t real system complexity.

2. Su-Field model

Product is the carrier of function, the function is the manifestation of product. In the 1940s American engineer Myers first puts forward the concept of function, and put it at the core problems of value engineering research.

The analysis of Su-Field is an important analytical tools in TRIZ, the basis of the analysis uses graphics instead of pending system to describe the system function. A system usually has multiple functions, the establishment of Su-Field model is required for each function and then the standard solution is used for solving the problems. Altshuller concluded: (1) the functions of the system can be decomposed into three basic elements (two substances and one field)in the TRIZ;(2) a certain function must be consist of these three basic elements;(3) a function can be formed organically by these three basic elements.

The function is divided into four types in TRIZ [1]: effective complete functions (Fig.2 a); Incomplete function (Fig. 2 b); ineffective complete function (Fig. 2c); harmful function (Fig.2 d).

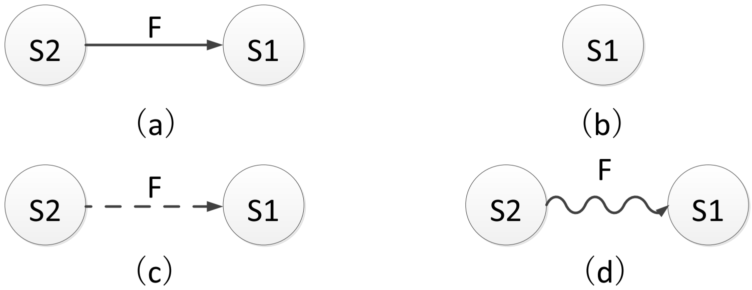


Fig 2 a variety of functional model

3. Establish integration process model between Design-Centric Complexity theory and Su-Field model

The system is decomposed to the typical components from the function analysis and find out the problems existing in the system. According to the definition and classification of complexity in DCC theory, the system problems are described by the complexity of corresponding design process; then converted to Su-Field model in TRIZ for decreasing the system complexity, in the end the process model is set up by integrating the design process complexity theory and Su-Field model in TRIZ. The concrete steps are as follows:

I. Decompose target system, determine the system problems, definite and classify the complexity according to DCC theory; From the perspective of function model, functionally decompose the system, divide the system into subsystems and decompose the subsystems until the inseparable element, as shown in figure 3.1. According to the requirements of user and the product design, find the problems in the system and the components involved in the system.

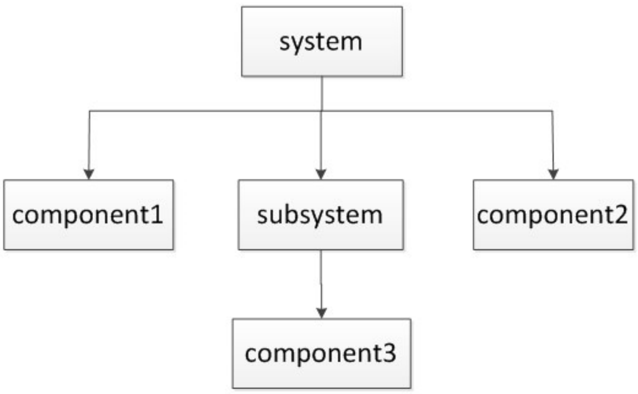


Fig. 3.1 System decomposition

II. Convert the complexity of the system into material - field model;

Correspond the type and the complexity of the Su-Field and TRIZ theory, establish Su-Field model for analysis.

III According to the Su-Field model, solve the model by corresponding standard solution.

Based on the Su-Field model, find out the corresponding solution by the 76 standard solutions, achieve complete function model to decrease the system complexity, as shown in figure 3.2.

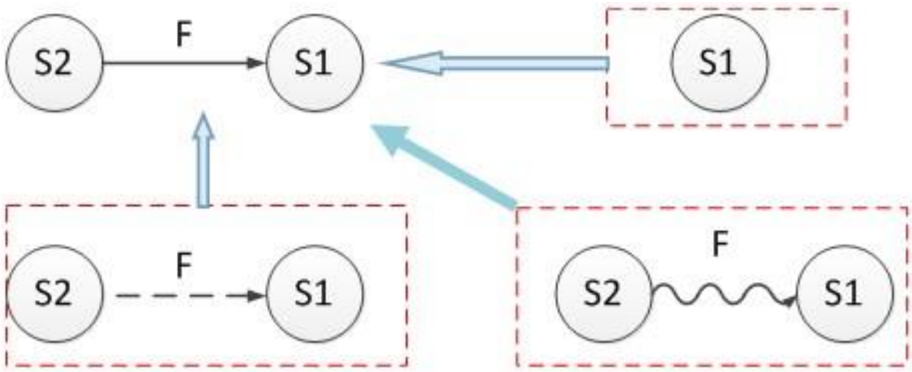


Fig 3.2 To effectively complete model transformation problem model

4 Case study

Nowadays since the German government put forward the strategy of "Industry 4.0", countries gradually raised a global upsurge of "Internet+", including China. Our country also puts forward "made in China 2025".Under the background of a more and more rapidly pace of life today, People prefer to nutrition improvement of a healthy diet. But now most of people are doing all kinds of porridge according to their own subjective consciousness.

Therefore an Auto-Mixed Systems of porridge needs to Develop Urgently to substitute manual work. The product should be simple and convenient, meet the gradually rapidly pace of the life and work, and satisfy people the different preferences of porridge. What's more, according to the special groups of customers (such as diabetes, etc.) requirements, it can provide the correctly kind of porridge. At the same time, application of "Internet +" concept, it can realize the remote control, and realize the customer to make an appointment. The Auto-Mixed Systems of porridge was rare at present, having a strong innovation. There are more vast development space and broad market.

I. To decomposition of the Auto-Mixed Systems of porridge system, determine existence problem of the system, and defines the complexity problems

Get the representative components based on system decomposition such as table 4.1.

Table.4.1

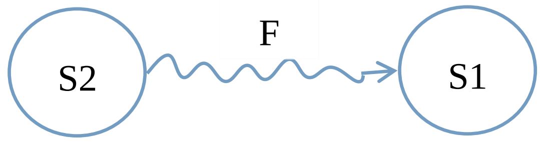
The representative components of the Auto-Mixed Systems of porridge system

serial number	components	function	effective object	Function type	Problem function
1	substructure	support	material storehouse	Standard	
2	substructure	support	Material box	Standard	
3	substructure	support	stepping motor	Standard	

4	substructure	support	microcomputer	Standard	
5	top head	connect	material storehouse	Standard	
6	stepping motor	connect	block material B	Standard	
7	block material B	contact	block material A	insufficient	√
8	clutch	connect	shaft	Standard	
9	shaft	connect	block material A	harmful	√
10	clutch	contact	microcomputer	Standard	

The analysis shows that the device structure, the diameter of the block material A is more twenty times than shaft, and connected directly causing the deformation of block material A and instability of the structure. The system has complexity, as the time increasing, the deformation of block material A and instability of the structure are added, and complexity increases, It have harmful effects on equipment. According to the theory of DCC complexity in the definition, the complexity is the time-dependent combinatorial complexity.

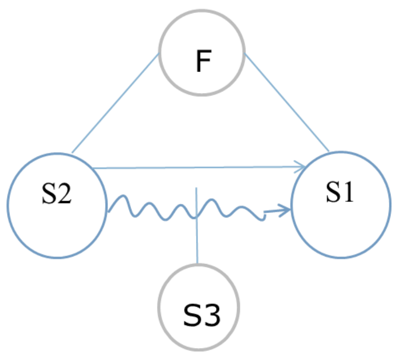
II. Su-Field model is established based on the time-dependent combinatorial complexity Depending on the complexity, Su-Field model is set up as shown in figure 4.1.



S1——block material A ; S2——shaft ; F——Mechanical field

Fig. 4.1 harmful Su-Field model

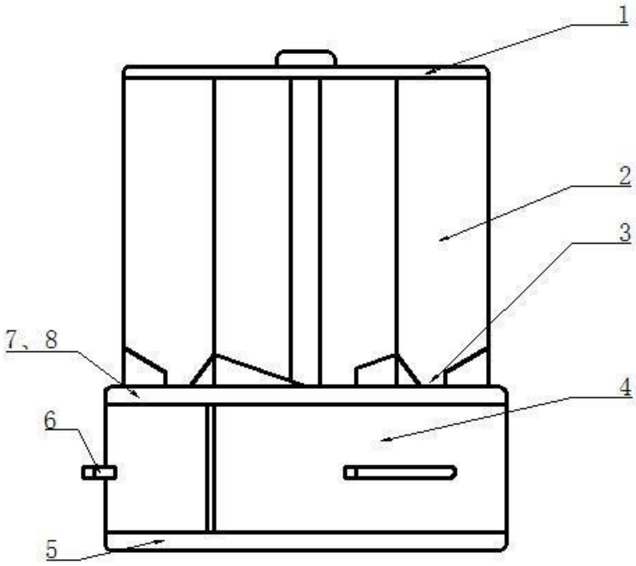
III. Combined with the standard solution to find the solution



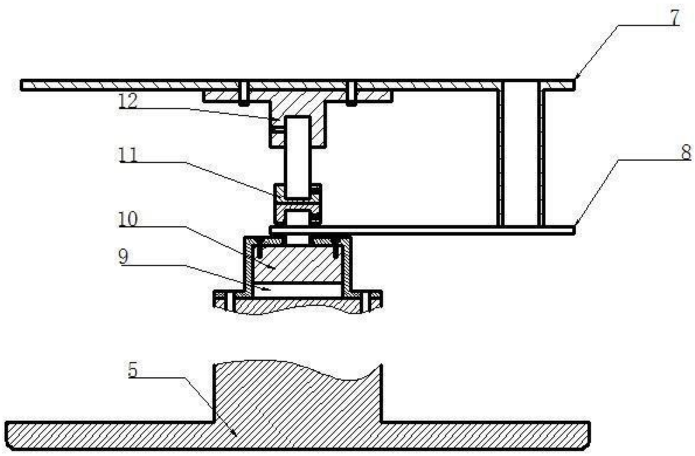
S1——block material A ; S2——shaft ; F——Mechanical field;S3——flange plate

Fig. 4.2 The improved of Su-Field model

Using substance-field analysis and 76 standard solutions, a convex flange is introduced, with the shaft directly, and then meet the block material A to eliminate harmful effect, at the same time, it can strengthen the block material A rotational stability. The overall effect is as shown in figure 4.3 and figure 4.4.



1-top head；2-material storehouse；3-asymmetric feed opening；4-Material box；5-substructure；6- Material box handle；7-block material A ；8-block material B Fig. 4.3 the overall effect schematic diagram



5-substructure；6- Material box handle；7-block material A ；8-block material B;

9-Battery；10-stepping motor；11-clutch；12-flange plate

Fig.4.4 the main cutaway view of substructure schematic diagram

Conclusions

From decompose target system, determine the system problems, definite and classify the complexity according to DCC theory; Convert the complexity of the system into material - field model; According to the Su-Field model, solve the model by corresponding standard solution.The validity of method is proved by the "Auto-Mixed Systems of porridge ". It provides a new direction and lays a foundation for the new product design and innovation.

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SYNCHRONOUS RELUCTANCE MACHINE ANALYSIS AND ELECTRIC MACHINE FORECASTING USING TRIZ

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Abstract

Electrification has been a rising trend in industry so that old and new solutions are constantly reviewed to improve reliability, efficiency and cut costs. A relatively recent solution proposed for applications ranging from small appliances to industrial motors, from fluid pumps to traction applications is represented by Synchronous Reluctance Machines: in their classical layout of a stator wound like any classical AC machine coupled to a peculiar rotor structure characterized by the alternation of iron ribs (so called "flux guides") and empty rotor slots (named "flux barriers"), these are brushless devices with no rotor windings nor expensive rare-earth magnets, they offer advantages from the robustness, efficiency and cooling requirement viewpoints, but a too low power factor, which ultimately translates into higher voltage and/or current rating (and cost) of the power electronics devices that will supply the machine. Rare-earth magnets are an expensive option and present brittleness and handling issues. Moreover, the fast rise in price experienced by rare-earth materials in the early 2010's, though now recovered by a fair amount, has raised concerns in the industry about their future price volatility and affordable supply-chain.

Since interest in low cost solutions grows steadily, one good compromise is represented by the adoption of ceramic permanent magnets, i.e., ferrites: a ferrite-assisted Synchronous Reluctance machine can be a solution for many applications where ac drives are required, since a relatively small amount of magnet can help improve the power factor and, to some extent, also the efficiency of the drive. Nevertheless, the rather low (with respect to rare-earth options) energy content of ceramic magnets poses a threat of demagnetization, especially due to the large peak currents arising in the first instants after a fault in the drive system supplying the machine or in the stator winding itself, so a thorough TRIZ analysis was implemented to understand the failure root causes and identify innovative solutions to protect magnets.

In this paper the full TRIZ problem identification process will be presented, considering the initial high-level engineering contradictions posed by classic and Rare-Earth Permanent Magnet Synchronous Reluctance Machines; then focus will shift to the detailed TRIZ tools adoption, i.e. Functional Analysis, S-Curve and Cause Effect Chain analysis, for a ferrite-assisted Synchronous Reluctance Machine, for effective contradiction identification. It will be shown how this pre-processing activity can help formalizing structures and diagrams typical for many analogous engineering systems and thus could be generalized to a wider class of electric machines and drives configurations. Moreover, the suggested inventive principles resulting from contradiction resolution could offer not only targeted solutions for the specific problem, but also shed light on possible pathways for future research, identifying the necessary technological enablers for the next steps in electric machines and drives development.

Keywords: TRIZ, Electric Machines, Synchronous Reluctance Machine, Forecasting

1. Introduction: Electromechanical Device R&D and market needs

Gieras [1] states that electric machine technology, that enjoys around 170 years of uninterrupted development, can be classified as a slow moving industry and as such, still profits from continuous improvement; in TRIZ words, it means that at present electric machine development activity has reached the 3rd stage of development with respect to nearly every Main Parameter of Value, i.e. energy conversion, efficiency and reliability for all electric machines, and torque generation and stator voltage generation for respectively motors and generators. For most of the applications in fact, by means of a simple S-Curve analysis [2] we can confirm that the 3rd stage evolutionary indicators [3], and in particular: the system has reached some development limits, is used in many areas, combines with many alternative systems, uses highly specialized resources, many super-systems component are design to accommodate the engineering system and MPVs change relatively slowly, are verified for all the listed MPVs. Evolutionary stage suggestions indicate as profitable directions design optimization for continuous improvement and deep trimming and switch of principle of action for more disruptive results. Example of new physics employed for the same main functions exists, but either they do not cover the same application spectrum, like i.e. solar power generation, piezoelectric, magneto-strictive and memory shape material based applications [1], or still find themselves in the first or transitional stage of development, like magneto-hydro-dynamic devices [4] [5]. So even if mature, electric machine technology still offer huge potential of development. Consistently, researchers lately focused on incremental optimization, with the goal of implementing an efficient magnetic circuit able to maximize the energy conversion, limited by the fact that the design activity is mainly driven by the material features and sees upper boundaries set by copper and aluminum electric conductivity and magnetic iron and steel saturation. Another aspect is the increasing integration with the adjacent power electronics discipline and system optimization [6], as well as multidisciplinary design that integrates thermal, mechanical and vibration aspects. Progress will be in the future sustained by new materials, new applications areas and technology challenges; the most recently developed solutions address high power density and high speed applications, portable power applications, medical and clinical applications, superconducting devices. According to [1] going forward the development of electromechanical devices will follow the requirements of computer hardware, like cooling fan and hard disk drive motors, residential and public applications like home appliances, HVAC (Heating, Ventilation and Air Conditioning) and distributed generation applications, and the increasing trend of electrification of transport means, i.e., electric hybrid vehicles, marine propulsion and electric aircrafts. In additions, there are the emerging fields of mechatronics and MEMS (micro-electromagnetic devices). TRIZ at this stage can be very useful to guide identifying new solutions, so in the next paragraph a full TRIZ analysis and Problem solving process is developed for a specific market driven example, to be compared step by step by a generalized electric machine TRIZ model, to be used in turn as a baseline for future projects and a helpful tool for forecasting analysis.

2. TRIZ applied to Synchronous Reluctance Machines for failure prevention

2.1. Device features

Synchronous Reluctance machines in their standard layout are brushless devices with no rotor windings nor expensive rare-earth magnets and offer advantages from the robustness, efficiency and cooling requirement viewpoints, but a too low power factor, which ultimately translates into higher voltage and/or current rating (and cost) of the power electronics devices that will supply the machine. They have been recently proposed for applications ranging from small appliances to industrial motors, from fluid pumps to traction applications in their classical layout of a stator wound like any classical AC machine coupled to a peculiar rotor structure characterized by the alternation of iron ribs (so called “flux guides”) and empty rotor slots (named “flux barriers”); rare-earth magnets are an expensive option and present brittleness and handling issues. Moreover, the fast rise in price experienced by rare-earth materials in the early 2010’s, has raised concerns in the industry about their future price volatility and affordable supply-chain. Even if this phase is recovering, interest in low cost solutions has raised steadily, so more conventional motor configurations like synchronous reluctance machines [6] have been reconsidered as viable alternatives, since they offer a simple passive structure with low losses and simple control, though their main drawback is represented by the low power factor. One good compromise is represented by the adoption of ceramic permanent magnets, i.e., ferrites: a ferrite-assisted Synchronous Reluctance machine can be a solution for many applications where ac drives are required, since a relatively small amount of magnet can help improve the power factor and, to some extent, also the efficiency of the drive. Nevertheless, the rather low (with respect to rare-earth options) energy content of ceramic magnets poses a threat of demagnetization, especially due to the large peak currents arising in the first instants after a fault in the drive system supplying the machine or in the stator winding itself, so a thorough TRIZ analysis was implemented to understand the failure root causes and identify innovative solutions to protect magnets.

In the view of the TRIZ analysis the Main Function for such a motor is “rotate shaft”. The following Component Analysis reflects this statement.

2.2. Component Analysis

Since the focus of this analysis is not the operation of the whole drive but the magnet failure prevention the system is considered as the assembly of components that form the magnetic circuit and the fields. Other components like the converter, the power supply, the control and cooling subsystems belong to the super-system as shown in Figure 1. For this specific application it was decided not to include the thermal field and the mechanical/vibration effects in the analysis; even if they are present in every electromechanical device, they don’t play a major role in this machine, nor are they relevant to the issue under study.

	System Component	Supersystem Component
1	Rotor	Rotor Shaft
2	Stator	Air
3	Stator teeth	Tension rod
4	Stator coils	Steel housing
5	Rotor ferrites	Cooling liquid
6	Rotor control coils	Control system
7	Magnetic field	Converter
8	Stator coil current	
9	Control coil current	
10	Stator coil insulation	

Fig. 1. Component analysis for Synchronous reluctance machine PM fault prevention

2.3. Function Analysis

The system, though simplified, is already composed by 17 components, resulting in a rather large 17 x 17 interaction matrix, which helped completing the Function Analysis as reported in graph form in Figure 2, where harmful function are reported in red (all correspond to the heat function unless written otherwise) and useful functions in blue; this kind of machine is essentially naturally air cooled, so the component Air in in contact and cools all objects; conversely, all objects heat air; this has been drawn aside with no starting/target component to ease the graph readability.

Energy conversion is achieved by means of a rotating magnetic field, resulting from the superposition of rotor and stator magnetic field contributions. In this model stator and rotor magnetic fields have been considered as separated for generalization purposes. The torque generation is actually performed by the component given by their sum or combination, and this has been accounted for with a light green rectangle.

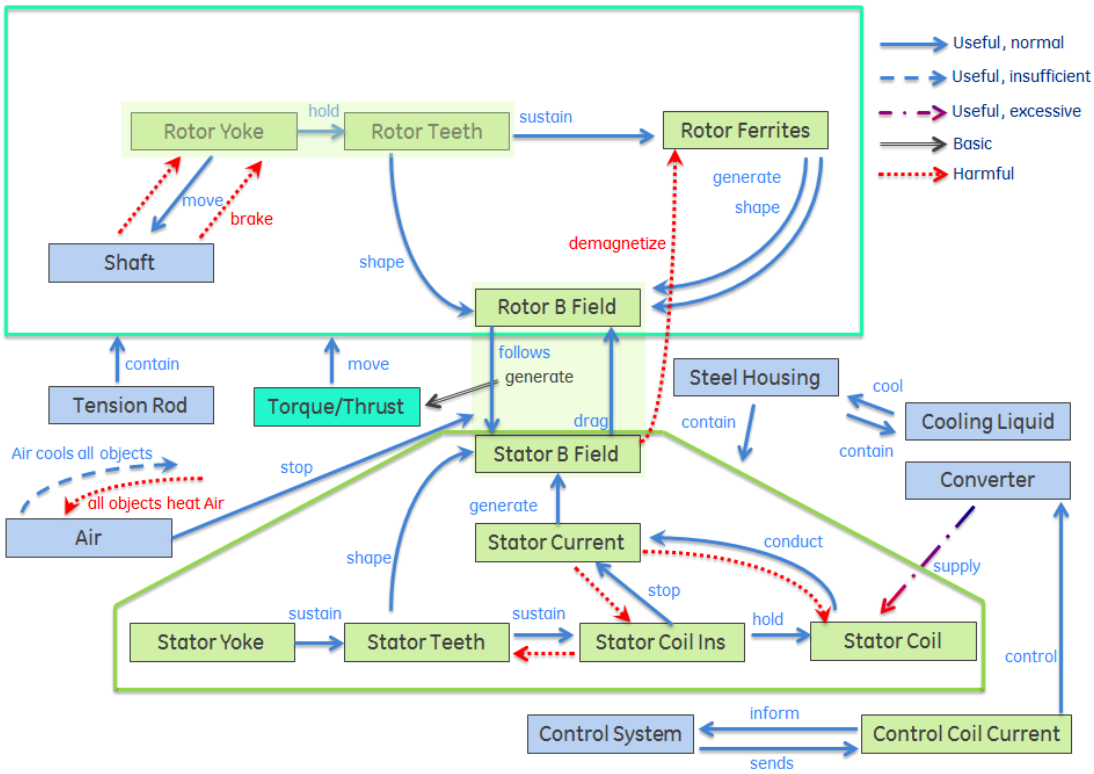

Fig. 2. Function Analysis for a Synchronous Reluctance Machine

It can be noticed that in this case all the auxiliary functions are performed in a sufficient way, already reaching the limits imposed by material characteristics; the cooling, which represents another bottleneck in the machine development, is instead always insufficient and it is bounded to copper characteristics, which essentially limit the thermal performance. Another disadvantage is represented by the excessive function (visualized by a gradient arrow) exerted by the converter supplying the stator coil which actually represents the problem we want to avoid. The disadvantage list is shown in table form in Table 1. The list of Disadvantages already provides the starting point for the Cause Effect Chain Analysis.

Table 1. List of Disadvantages

Harmful functions	**Useful Functions**
Steel housing conducts Stator Magnetic Field	Air cools Rotor (I)
Shaft brakes Rotor	Air cools Stator (I)
Stator Coil Current heats Stator Coil Insulation	Air cools Stator coils (I)
Stator Coil Current heats stator Coils	Air cools Ferrites (I)
Stator B Field demagnetizes Rotor Ferrites	Converter supplies Stator Coil Current (E)

(I): insufficient performed functions, (E): excessively performed functions

2.4. Cause Effect Chain Analysis

The Main Goal of the project was defined as “It is necessary to minimize the demagnetization of the permanent magnets”. Since no other major issues emerged from the Disadvantage Analysis (being most of the listed one issues common to all electric machines but not addressing the specific problem), the cause Effect Chain Analysis started from the main Disadvantage and the diagram was built as reported in Figure 3. It can be observed that the diagram reports very early a key disadvantage the magnetic properties of the ferrites (low magnetic coercivity of materials), dictated by design choice and physics. An intermediate disadvantage is given by the short circuit condition, as well as the excessive current supplier by the converter for the same condition. The diagram presents OR loops, so no easy trimming can help. The stator current provided by the inverter represent the component where the key disadvantage occurs. A conservative approach has been taken, writing contradictions around it rather than going for a radical trimming, one formulated as an engineering contradiction (EC) and one as physical contradiction (PC). Both have been considered twice: the EC has been reformulated using different parameters that capture the same physics. For PC the two options of Separating Contradictory Demands in Relationship and Satisfying Contradictory Demands, as reported in Figure 4. The identified specific solutions are proprietary to GE, nevertheless the suggested inventive principles considered relevant to the problem can be grouped into two categories, one addressing the control part acting key disadvantage regarding the PM- d-axis alignment, and one referring to material development or smart utilization:

• Control: 11- In Advance Cushioning, 19- Periodic Action

• Materials: 36- Phase transitions, 40- Composite Materials, 31. Porous materials, 35 – Parameter changes

Other listed inventive principles, i.e., 2- Taking Out and 28. Mechanic substitution point to too radical intervention for the scope of this project, thus they suggest to consider the development of new topologies. This selection agrees with the statements discussed in Paragraph 1., where better integration with the control and supply system and material development have been identified as the present most promising short- and mid- term innovation directions for the electric machine field. In order to have a better insight and reinforce this, the analysis has been extended to a generalized electric machine.

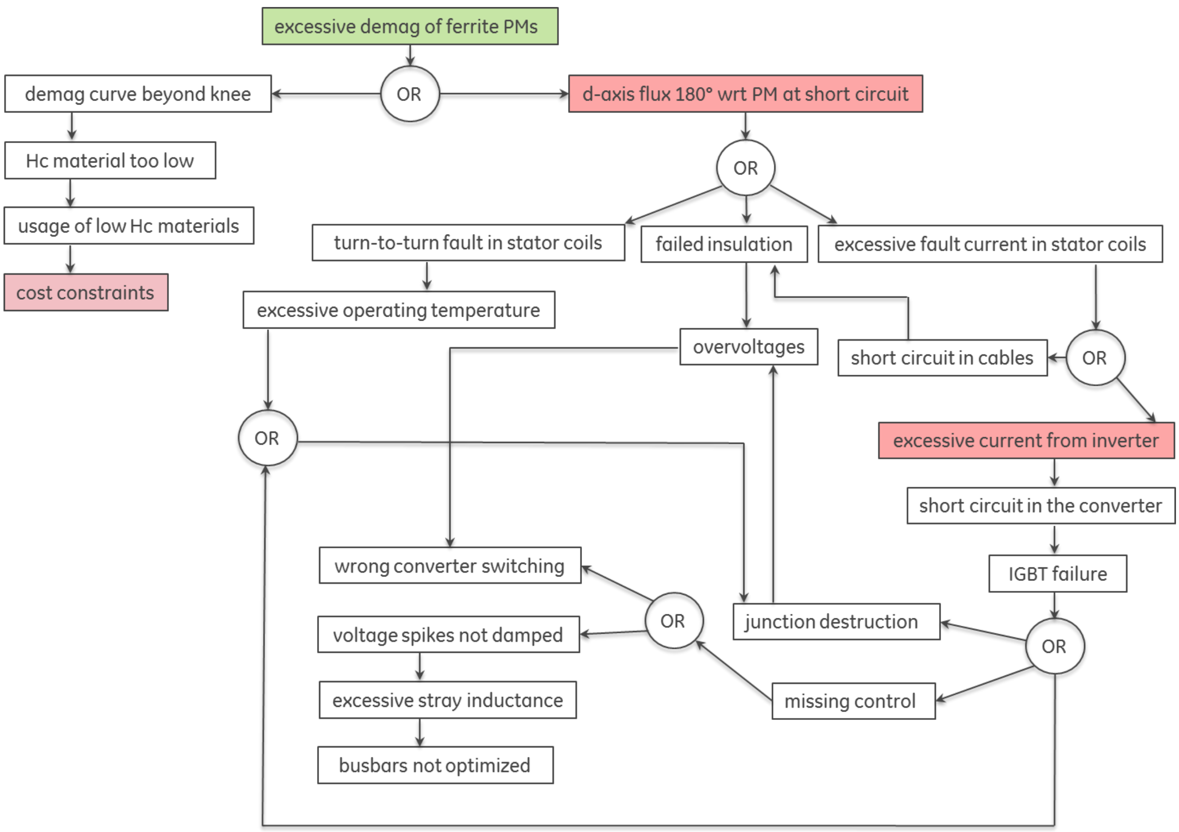

Fig. 3. Cause Effect Chain Analysis

Engineering Contradiction	Improving	Worsening
current is high magnetic field magnetic load damages magnets	torque	magnetic load on PMs

Improving	Worsening	Inventive Principle
force	tension/pressure	18. mechanical vibration 21. skipping 18. in advance cushioning

TRIZ generalized model of contradiction and solution

Improving	Worsening	Inventive Principle
tension/pressure	loss of energy	2. taking out 21. phase transition 25. self-service

	Physical Contradiction
component	stator coil current
should be	there
In order to	produce rotor magnetic field
BUT	
component	stator coil current
should be not	not there
In order to	trim current/ power electronics

Separating contradictory demands (Relation)

40. composite materials
31. porous materials
32. color changes
3. local quality
19. periodic action
17. another dimension

Satisfying contradictory demands

36. phase transition
37. thermal expansion
28. mechanics substitution
35. parameter changes
38. strong oxidants
39. inert atmosphere

Fig. 4. Engineering and Physical Contradictions

3. TRIZ applied to a Generalized Electric Machine

3.1. Problem Definition

Rotating and Linear Electric Synchronous and Asynchronous Machines are all built according to the same principle and share the same description for most of the physical phenomena implementing the required electromechanical conversion, being it electrical-mechanical in motors or mechanical-electrical in generators [8]. For this reason a generalized model is built, representing a machine as the interaction of two electromagnets or as an electromagnetic joint [9]. Common project goals in this field are: increase power density of the device, decrease cost, prevent full outage and increase reliability. Usual restrictions and limitations are represented by material properties (saturation and thermal limits), operating voltage and frequency (established by standards and power electronics requirements), operating temperature and cooling system rating.

3.2. Component and Function Analysis

The component list has been updated and generalized building up on the model for the synchronous Reluctance machines, as shown in Figure 5: only the electromagnetic circuit and fields have been considered; The system component list has been extended to all magnetic and electric components usually present in an electromagnetic device, including the eddy current fields for both Stator and Rotor Coil and stator and rotor yoke, in such a way to obtain a symmetric model that could serve both the motor and a generator description. For the same reason two targets have been identified, Torque/Thrust (mechanical field generation) and Stator Coil Voltage (electric field generation), representing respectively the motor and the generation operation. A complete list would have required also the thermal field and its interactions with all the components, the mechanical damping system and the supply and control power electronics: the involved fields and components have been grouped into the corresponding super-system component, namely: cooling system, damping system, control system and power electronics interface. A measuring and diagnostics subsystem component, the mechanical frame and the acoustic field have been added to the super-system to complete the picture. The thermal behaviour has been accounted for by means of functions, so no temperature/heat field is added to the component list.

1	System Component	Supersystem Component
1	Rotor yoke	Torque/thrust
2	Rotor teeth	Stator Coil Voltage
3	Rotor (Electro)Magnet	Surrounding Air
4	Stator yoke	Shaft
5	Stator teeth	Cooling system
6	Stator (Electro)Magnet	Damping system
7	Rotor EM insulation	Control system
8	Stator EM insulation	Power Electronics Interface
9	Rotor B Field	Measure & Diagnostics
10	Stator B Field	Mechanical Frame
11	Stator Current	Acoustic Field
12	Rotor Current	
13	Eddy Current Stator EM	
14	Eddy Current Rotor EM	
15	Eddy Current Stator	
16	Eddy Current Rotor	

Fig. 5. Component Analysis for a generalized electric machine

The goal is to obtain a master model to be specialized for any specific application, with the option of removing the not relevant component or detail in more depth the subsystems as needed. Stator and Rotor (Electro)Magnets ("EM" in Fig. 6) are the generalized components responsible of the field generation: in this way they can represent coils in classical wound machines, a squirrel cage for induction machines or permanent magnets or even the combined use of both. The resulting functional analysis diagram in Figure 6 reflects the same approach.

Consistently with the function analysis for the synchronous reluctance machine, also in this diagram harmful functions are reported in red and indicate the function "heat" unless written otherwise); basic functions are depicted in black; useful functions are represented by blue arrows; surrounding air and the cooling system are separate components in order to account for liquid cooling or forced air; both have been drawn aside with no starting/target component to ease the graph readability. Focus is on the electromagnetical behaviour and the electromechanic conversion, so the subsystems control, power electronics interface, machanical frame, vibration damping, acoustic field are all reported in the graph, but their interaction with all other components has not been deepened. The model is thought to be reversible and represent both motors and generators. So the functions between Stator and Rotor magnetic field (drag/follow) are interchangeable according to the considered operation. In this view we can consider the function analysis of the synchrounous reluctance machine in Fig 2. a subset of the generalized model in Fig.6.

3.3. Typical Disadvantages

The function analysis allows identifying some initial disadvantages, i.e. the heating of most components with raise in temperature and material/performance deterioration, deformation of magnetic fields that impairs energy conversion efficiency, eddy current losses.

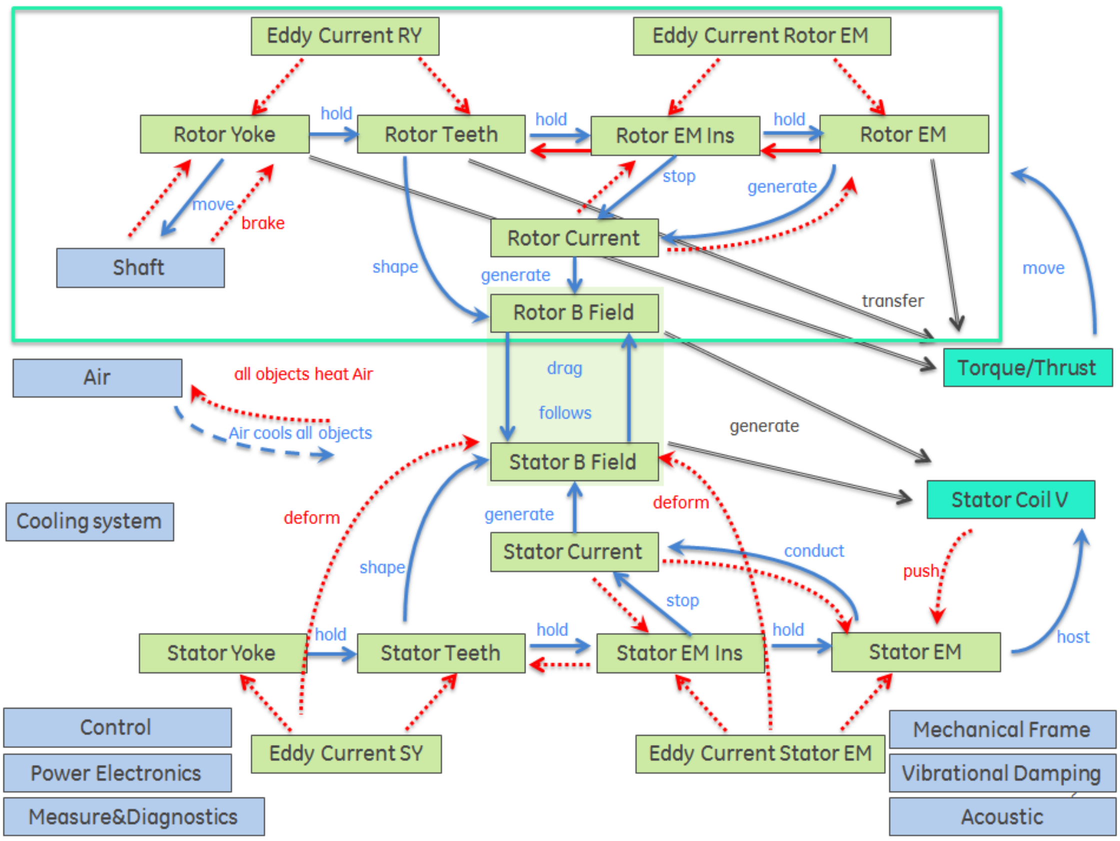

Fig. 6. Function Analysis for a generalized electric machine, same arrow and color code as Fig 2,

In addition, in electric machine development the most common issues to address, that also define the most pursued directions of optimization, are:

- Insufficient power density
- Excessive cost
- Emerging full outage
- Insufficient reliability

The biggest challenge though is represented by the thermal management: with this respect the problem can be formulated as a physical contradiction, since the electric current and the dynamic magnetic fields are both necessary to implement the electromechanical conversion based on the electromagnetic induction and responsible at the same time for ohmic and eddy current losses, which in turn represent the major contribution to the machine heating. So both (Electro)Magnets and Stator/Rotor Moving Magnetic Field should be there and not to be there at the same time. Separation in Time and in Space do not represent viable ways to solve the basic contradictions. All other methods, respectively Separating at System Level, in Affiliation, in Direction, Satisfying Contradictory Demands and Bypassing Contradictory Demands suggest a set of principles, that can be in turn grouped into four groups:

1. Addressing Machine Topology: 1- Segmentation (x2), 19- Merging, 33- Homogeneity, 3- Local Quality, 17- Another Dimension (x2), 4- Asymmetry, 14- Curvature, 28- Mechanic Substitution, 35- Parameter Changes, 37- Thermal Expansion, 13- The Other Way Round

2. Addressing Materials: 33- Homogeneity, 40- Composite Materials (x2), 31. Porous materials, 32- Color Changes, 3- Local Quality, 35- Parameter Changes(x2), 36- Phase Transitions, 37- Thermal Expansion

3. Addressing Control: 12- Equipotential, 19- Periodic Action, 32- Color Changes, 35- Parameter Changes

4. Others: 38- Strong Oxydants, 39- Inert Atmosphere, 25- Self-Service, 6- Universality

4. Conclusions and further developments

The outcome of this work and envisioned developments can be outlined as follows:

- Literature research and S-Curve analysis show how electric machine industry can be described as slow developing and mature (3rd stage): so it can benefit from both incremental and disruptive approaches: innovation is pushed by small motor industry and transportation application (electric vehicle, unmanned vehicle, more electric ships and aircrafts)
- A full TRIZ model for a specific machine, a ferrite-assisted synchronous reluctance (SRM) one, has been derived; inventive principles suggest different set of solutions, identifying enablers for new classes of devices that would allow the present electric machine technology to jump on the next S–Curve. Others solutions address the control strategy. More disruptive solutions could be enabled by new materials or strategies that allow changing of circuit topology during operations as already applied in fault-tolerant applications as described in [10].
- A model for a generalized electric machine is derived, for which the specific one (SRM) is a subset, identifying the principles to be applied to the different directions

of optimization, addressing material science, magnetic and electric circuit topology and control, useful for incremental and disruptive innovation and forecasting

- Implement specific solutions and test the electric machine generalized model on other specific examples

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THE IMPACT OF DIFFERENT TRIZ TOOLS ON THE CREATIVE OUTPUT OF STUDENTS

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Abstract

Innovation needs to be taught to students from technical and also non-technical education streams. The emphasis of innovation education should be on developing creative problem-solving skills instead of just the learning of science, technology, engineering, and mathematic subjects. In recent times, more research works are being done on the teaching of innovation to students using the Theory of Inventive Problem Solving (TRIZ). Current research work mainly emphasizes on teaching TRIZ to engineering students, and only a few tools are being taught to them. This research aims to develop a TRIZ-based innovation subject and measure its impact on the creative output of students. TRIZ tools such as the 9-Windows, S-Curve Analysis, Ideality, Contradiction Matrix, 40 Inventive Principles, Function Model, and Trimming were taught as a subject that was offered to the undergraduate students in a university. A total of 230 first-year undergraduate students from the faculties of engineering, applied science, computer science, and business enrolled in the subject. Their creative output was measured based on the innovation level of their projects. A new tool called the Eco-Ideality Analysis Chart was developed to assist in this evaluation. It is found that the projects did improve with the usage of more TRIZ tools. The students have also obtained different creative problem-solving skills with the learning and application of the various TRIZ tools.

Keywords: Education, Design Process, Conceptual Solution Evaluation

1 Introduction

Innovation is an increasing necessity in any domain of human progress and development. The education system would need to train up more students to be innovative. However, there is a worrying decline of students enrolling into technical subjects that are related to science, technology, engineering, and mathematics (STEM) at the tertiary education level.

STEM subjects are known to be the engine of innovation. With knowledge being increasingly accessible through information technology, the memorization of knowledge contained within these technical subjects are not as important as the skills in applying them to develop new innovations. Being more innovative requires not just a good grasp of technical knowledge. It requires mastery of creative problem-solving skills. Knowledge gets outdated and updated with time, but skills get sharpened over time.

Among all of the programs offered at the tertiary education level, the engineering program best represents STEM. Engineering is the application of science and mathematics to develop innovatively practical technologies. Current engineering students rarely obtain any experiences related to creativity during their study. They are discouraged from taking creative risks because of the rigid structure of the curriculum and the high expectations placed on them to get things right at all times [1]. Therefore, leading to highly standardised outputs from the students.

The engineering curriculum has always been reformed to increase the number of engineering topics [2]. By doing so, engineering programs become isolated and highly specialized according to those various topics [3]. Therefore, enrolling in a degree program that involves highly specialized technical knowledge such as engineering could instead adversely affect a student's creativity and also limit the areas of application. To possibly increase the enrollment of more students, STEM subjects need to be able to teach them to innovate in wider instead of narrower application areas.

Every innovation solves a problem by creating a way which is better and more novel than any other existing solutions. Therefore, the essence of innovation is creative problem solving. There is a need to equip students with creative problem-solving skills to enable them to innovate continuously. The technical knowledge lacked can be easily accessed these days. However, creative problem-solving skills could not be accessed immediately and would need nurturing from

Theory of Inventive Problem Solving (TRIZ) is well known to consist of design tools that can be used to solve problems systematically. It is proven to be effective in developing innovations at numerous types of industries. Besides being applied in industry, there is also an increasing utilization of TRIZ to educate students on innovation.

1.1. TRIZ in Education

More research are being done on the teaching creative problem-solving using TRIZ. There are research works related to teaching TRIZ to a diverse demographic of students. The students involved in those studies came mainly from colleges [4] and universities [5][6][7]. TRIZ has been taught to the students through seminars or as part of a subject offered in the university.

In most related research, only one or two TRIZ tools are taught to the students. The tools taught to students in previous research works are the 9-Windows [6][8], Contradiction Matrix, 40 Inventive Principles [5][9][10][11][12], S-Curve Analysis [8], Trends of System Evolution [5][10], and ARIZ [9]. The most common TRIZ tool being taught to the students is the 40 Inventive Principles. More tools need to be taught to the students in order to determine how these different TRIZ tools help them in developing innovations.

1.2. Research Gap

There are two main gaps in existing research related to TRIZ in education. Firstly, only limited types of TRIZ tools were included in the previous research. In industry practice, a combination of TRIZ tools is used to develop solutions to problems. The usage of the various TRIZ tools by the students need to be investigated.

Secondly, there is a lack of study of the actual impact of the various TRIZ tools on the creativity output of the students. Each of the tools was developed for specific purposes in a problem-solving process. How the different TRIZ tools affect the creativity of the students has to be qualitatively and also quantitatively determined.

This research aims to increase the creative problem-solving skills of the students by teaching them TRIZ tools. The strategy is to teach them different varieties of TRIZ tools. Their creativity output is measured indirectly by evaluating the design solutions developed by them after using TRIZ.

2 Methodology

A TRIZ-based syllabus to increase the creative output of students is proposed. The TRIZ tools suggested for the framework are the 9 Windows, S-Curve Analysis, Contradiction Matrix, 40 Inventive Principles, Function Model, and Trimming. These tools represent a large portion of the complete tools currently available in TRIZ. All of these tools are grouped into three toolsets as shown in Table 1. The intended purpose of the selected TRIZ tools explains the sequence of activities that the students will go through. These activities mimic the design stage in a standard product development process.

Table 1 TRIZ Toolsets

TRIZ Toolset	**TRIZ Tools**	**Intended Purpose**
Toolset A	9-Windows	Identify similar products that are in the past and present.
	S-Curve Analysis	Find the existing product in the market that should be the project's benchmark.
	Ideality	Develop conceptual designs that have higher ideality.
Toolset B	Contradiction Matrix	Help to identify contradicting problems in the existing benchmark and in the initial concept.
	40 Inventive Principles	Remove contradictions and improve product functionality.
Toolset C	Function Model	Identify any excessive or harmful function interactions within the system.
	Trimming	Simplify the system by making it more resource efficient.

The TRIZ toolsets were taught within an innovation subject offered to university undergraduates. In the past, TRIZ tools have been taught to mainly engineering students [5] [13]. For this research, the subject is open to students from any faculty to enroll.

2.1. Structure of the Subject

TRIZ was delivered on the subject over a period of three weeks. One toolset is taught to the students every week. Each TRIZ Toolset is covered over a three-hour lecture and a three-hour tutorial. The lectures were conducted in a workshop style. After each TRIZ tool had been taught, the students were given hands-on exercises to familiarize themselves with the tools. During the tutorials, the students were assigned to work on projects in fixed groups. The projects were carried out in the form of competition between the groups. The groups with the most creative and innovative project at the end of the semester will be awarded extra marks. Competition is found to enhance participation of students in a learning process [14].

Each group was tasked to work on their own project for the entire semester. For this subject, this research proposes that the students were allowed to choose their project topics freely. They may choose to further conceptually innovate any existing products that they think might improve their daily life. The ability to identify products that have the potential for innovation is also an important skill that needs to be learned. With that same project, they were expected to use the three toolsets to develop more creative and innovative design concepts.

The creativity and innovation level of the design concepts were evaluated in terms of the ideality of the conceptual design. In this research, a graphical tool called the Eco-Ideality Analysis Chart was developed to carry out this evaluation.

2.2. Eco-Ideality Analysis Chart

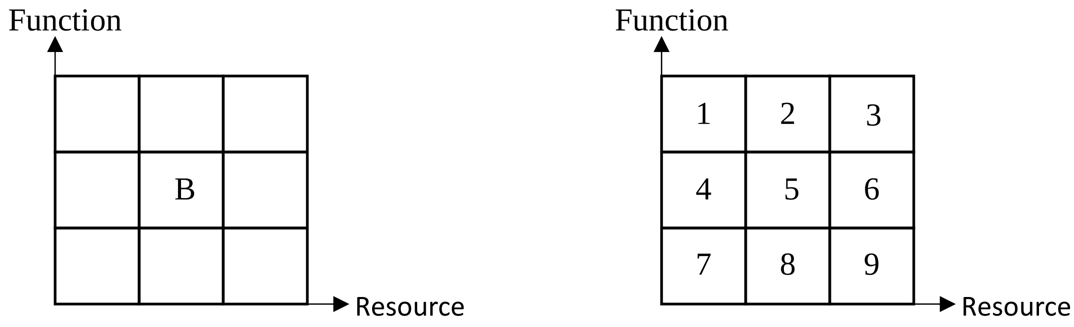
The Eco-Ideality Analysis Chart is based on the Ideality tool of TRIZ and the Value Analysis Chart which is under another design methodology called Value Engineering. The concept of Ideality is the ratio of a product's functionality over its cost and harm [15]. That is why Eco-Ideality Analysis Chart has axes that represent function and resource. The function axis represents the level of effectiveness of the product's main useful function. As for the resource axis, it represents the amount of resources consumed in making the product and in operating the product.

It's hard to use the Ideality ratio as an evaluation tool as the denominator and numerator are qualitative values. Scores and weights have been used before in putting a quantifiable value to the function and cost values [16]. This will provide a numerical value to the Ideality ratio. However, exact information on the value of the product's function and the cost of the resources used are first needed to do this scoring. Such information is often not readily available especially in the design stage of product development.

The challenge is to evaluate the ideality of a design without having this exact information. It is proposed that a qualitative comparison should be made between the conceptual design and a benchmark. The benchmark is the product or a design concept chosen by the students.

The Eco-Ideality Analysis determines if the function and resource consumption of the design concept have increased, decreased, or maintained in comparison to the benchmark. It is just based on the qualitative comparison. There are nine possible combinations of function and resource consumption as shown by the nine boxed areas in Figure 1a. The benchmark with the 'B' annotation is placed at the center of the chart.

The design concepts are given different Rank Scores depending on which box they are located in. These Rank Score values are from one to nine as shown in Figure 1b. The lower the Rank Score, the more ideal is the design concept. Rank Score of 1 is the most desired and Rank Score of 9 is the least desired. The function has higher priority than resource consumption because it is the reason the product was first developed. Therefore, the most desirable Rank Scores are in the highest row instead of the most left column in the chart.



a. The basic structure of the chart   b. The Rank Scores

Fig. 1 Eco-Ideality Analysis Chart

With the Eco-Ideality Analysis tool, the creativity and innovation level of the new designs by students can be gauged in terms of ideality. Hence, indirectly measuring the creativity output of the students. In the next section, the results of the projects developed by the students using the proposed three TRIZ Toolsets will be discussed. The evaluation of those projects using the Eco-Ideality Analysis will also be shown.

3. Results

A total of 230 students enrolled into this TRIZ-based subject. Over 80% of the enrolled students are from the engineering faculty, and the remaining are from the faculties of applied science, computer science, and business. Almost all of them are in their first year at university.

3.1. Projects

The students were formed into 34 groups. All of the groups chose different products for their projects except for a few who worked on the same products. The selected products were diverse in variety. Their project choices fall into six main categories and a further 10 subcategories as shown in Table 2.

The projects were continuously worked on by the students using the three different TRIZ toolsets proposed for this syllabus. The toolsets were used in sequence. After each toolset had been applied, newer conceptual solutions were developed. The groups were instructed to document their project's progress into separate reports for each of the three TRIZ toolsets. These reports contain the detailed steps of the application of the TRIZ tools into their project and also descriptions of any new conceptual solutions.

Table 2 Different Project Categories

Main Categories	**Sub Categories**	**Products**
Sports & Outdoors	Accessories (Outdoor)	Water filter
		Walking Cane
		Visual Assistant
Electronics & Computers	Electronics Accessories	Aircraft cabin lamp
		Information card
	Cell Phones & Accessories	Powerbank

		Phone cover
		Earphone
	Hardware	Shop scanner
		Payment system
	Computers Accessories & Peripheral	Computer mouse
		Translator device
Home, Garden & Tools	Kitchen & Dining	Food package
		Storage device
	Furniture & Décor	Wall switches
		Window
		Bench
		Chair cushion
Beauty, Health & Grocery	Health, Household and Baby Care	Detergent
		Oral care
Apps	Productivity App	Punctuality Reminder
	Service App	Parking notification
		Service recruitment
Automotive & Industrial	Industrial Supplies	Goggles
		Traffic notification

3.2. Rank Scores

The creativity output of the students is indirectly measured by evaluating the ideality of their design concepts. With the detailed descriptions provided in the reports, the innovation levels of the TRIZ-developed concepts have been assessed. The newly developed Eco-Ideality Analysis tool was used for this evaluation. Two main considerations on the concept's function and resource consumption were made in this assessment. This evaluation was carried out by the lecturers and tutors involved in this subject.

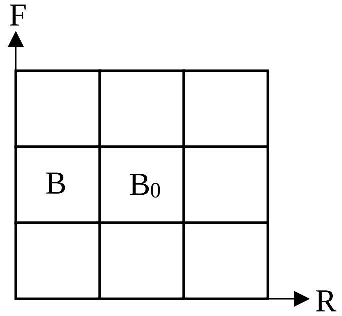
The Rank Scores were then given accordingly to each project based on the function and resource evaluation. Rank Scores were provided by comparing the functionality and resource consumption of the developed concept in comparison to the product benchmarks. There were two benchmarks. The first benchmark was the product that was already in the market which was initially identified by the group to improve. This original benchmark was given the annotation of B_0. The second benchmark was the best concept developed through the usage of the TRIZ toolset. These benchmarks for TRIZ Toolsets A, B, and C were given the annotations of B_A, B_B, and B_C.

Ranks Scores were given to all of the projects. These Ranks Scores were then summed together and then divided by the total number of projects to give the average Rank Score. The average Rank Scores given after each TRIZ toolset and for the different benchmarks are shown in Table 3.

Table 3. Average Ranks Scores for the Projects

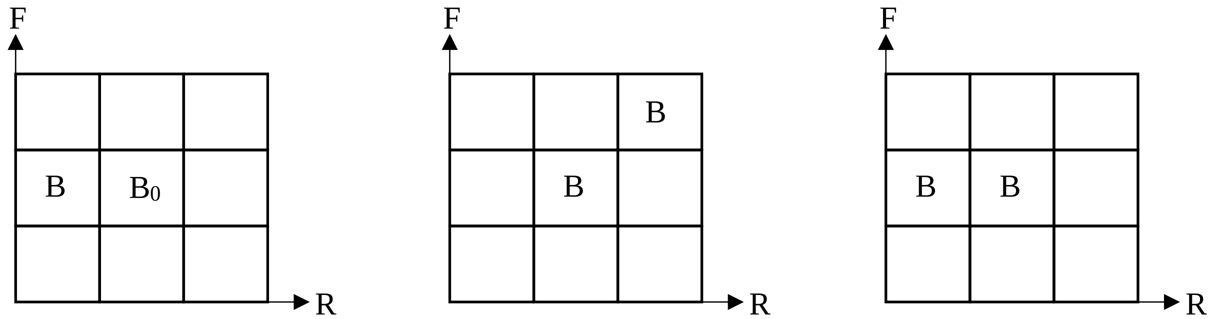
Average Rank Scores					
Toolset A		Toolset B		Toolset C	
Relative to Original Benchmark B_0	Relative to Previous Benchmark B_0	Relative to Original Benchmark B_0	Relative to Previous Benchmark B_A	Relative to Original Benchmark B_0	Relative to Previous Benchmark B_B
4.15	4.15	3.47	3.44	3.76	4.59

Based on the average Rank Scores, the Eco-Ideality Analysis Charts could be sketched. Figures 2 and Figures 3 show how the projects' conceptual solutions evolve in terms of the function and resource consumption levels after the application of each TRIZ toolset. Overall, the evolution of the conceptual solutions after each TRIZ toolset will be discussed in the next section.



a. Toolset A b. Toolset B c. Toolset C

Fig. 2 Eco-Ideality Chart based on B_0



a. Toolset A b. Toolset B c. Toolset C

Fig. 3 Eco-Ideality Chart based on B_A, B_B, and B_C

4. Discussion

This section provides the discussion of the average rank scores obtained after the usage of each TRIZ toolset. The discussion also includes how the students apply the toolsets, the challenges faced by them, and the various creative problem-solving skills developed after using the toolsets.

4.1. Toolset A

The average Rank Score achieved after the students used Toolset A was 4.15. This shows that with the toolset, the students managed to develop solutions that were less resource intensive compared to the original benchmark while maintaining the product functionality. This can be seen by the position of the Toolset A-based design concepts, B_A in Figure 2a and Figure 3a.

It was observed that by using the 9-Windows and S-Curve Analysis tools, the students were encouraged to review products that are similar to their initial product benchmark. They were then able to relate the functions performed and resources consumed by the group of similar products.

With the Ideality tool, the students were encouraged to develop products with better function and by using lesser resources. It was challenging for the students to design ideal concepts. Toolset A does not suggest principles on how to improve functions or how to reduce resource consumption. Neither does the toolset provide direct suggestions on how to solve the problems of the chosen benchmark.

The toolset has however indirectly guided the students to apply existing design solutions of similar products into their new design concept for their project. This has taught the student that innovation need not necessarily mean an entirely new solution. Innovation can be a new application of an existing solution. The key creative problem-solving skill is a hybridization of existing design solutions into a new application to solve design problems.

4.2. Toolset B

With Toolset A, the average Rank Score of 4.15 indicated that while the resource consumption is reduced, the function of the product did not improve. After using Toolset B, the average Rank Score of 3.47 was achieved in relative to the previous design solution, B_A. Relative to the project's initial benchmark, B_0, the average Rank Score of 3.44 was achieved. Both of these average Ranking Score indicates that function has improved but at the expense of higher resource consumption as shown in Figure 2b and Figure 3c. Generally, the higher resource consumption also indicates that a solution is now more complex as it is using more components to carry out the function.

Functions of products are hindered by design problems in the form of contradictions. There was function improvement with the usage of Toolset B because the tools are meant to solve contradictions. The Contradiction Matrix was built on the basis of synthesizing specific contradictions into general contradictions and indexing the most common principles used to solve those contradictions.

It was easier to apply Toolset B for the projects that were mechanical products. This is not surprising as the tools were based on mid-twentieth century patents of products and processes that were mostly mechanical based. Students with mobile application software as their project found it difficult to use Toolset B. It is hard to relate the contradicting parameters and the suggested inventive principles to software.

Toolset B has encouraged the students to identify contradictions in the design concepts that they develop. It has also encouraged the students to resolve contradictions instead of settling for a compromise. Instead of relying on their own experience to solve the contradictions, they have learned to apply the inventive principles.

4.3. Toolset C

The average Rank Scores are 3.76 when the Toolset C based concepts, B_C are relative to the original benchmark, B_0 and 4.59 when they are relative to Toolset B's concepts, B_B. Compared to B_0, the average Ranks Score of B_C is higher than B_B and is closer to Rank Score of 4. It indicates that the students developed concepts that less resource is intensive without compromising on the main function.

This is not surprising because Toolset C is meant to simplify the products. Simplification is achieved by trimming excessive components and unnecessary additional functions while maintaining the product's main useful function.

Building the Function Model encourages the students to understand the mechanisms and ways the product operates. Function Model works well when there are physical products. Initially, some groups face difficulty when modeling their products which are based on chemical or software. Subsequently, the students still manage to develop the Function Models by considering the chemical compounds and also the different software features as components. Though these are not tangible, the components do perform functions, and hence modeling could be done.

The students have acquired the skill of developing conceptual designs that are feasible and straightforward. By Function Modelling, the students develop understanding on how their products work and what components are needed to carry out the functions. The students now know how to source for available components or technology that will enable the product to perform as conceptualized in the simplest way possible.

4.4. Additional Observation

TRIZ consists of an increasing number of tools and concepts. With the vast selection of tools associated to TRIZ, it is assumed that a lot of time is needed to learn TRIZ and guidance from specialists are required [17]. There are also perceptions that due to the technicalities of TRIZ, it is, therefore, difficult, and this makes it hard to learn and apply it [18]. Through this research, it is shown that TRIZ could be taught to young students through a subject that takes three weeks to complete. They have shown understanding of the tools by applying them correctly in their projects.

A final exam is given at the end of the semester. This exam consists of questions meant to test the understanding of the students on the TRIZ tools. All of the students passed the exam. The good exam results also further suggest that students beyond the engineering faculty could understand the technicalities of the TRIZ tools.

The proposed TRIZ subject has achieved its purpose in delivering TRIZ in a way that it can be learned and applied by students from technical and even non-technical faculties. Also, it is shown that it does not take a long time to understand TRIZ. Even with only a total of 9 hours of lecture and 9 hours of tutorial, the students were able to learn and apply the tools into their projects.

5. Conclusion

Through this research, the importance of teaching a diverse range of TRIZ tools to the students in order to increase their creative output was revealed. The research explains in detail how the different tools impact the thinking process of the students. Their creative output after using the various TRIZ tools was also evaluated and analyzed.

5.1. Research Contribution

Overall this research work has contributed in terms of a developing a framework for a TRIZ-based syllabus to increase the creative output of students. The syllabus has mimicked the design stage of an actual product development process. It is found that the different TRIZ toolsets were able to be understood and used by the students beyond the engineering faculty.

This research has also contributed in terms of the development of a basic evaluation tool called the Eco-Ideality Analysis Chart. Because the chart is visual, an overview comparison of design solutions could be easily made. Such assessments could be done even though exact values of the function and resource are unavailable. The charts show that the design concepts develop by the students did improve after using the various TRIZ toolsets.

5.2. Future Improvements

For future improvement, further topics within the product development process should be embedded into the TRIZ syllabus. The current projects in the syllabus are currently only based on design concepts. As a requirement for future projects, the students should develop their TRIZ-based concepts further into prototypes. That will equip them with more problem-solving skills. Market feedback on the prototypes should also be obtained before possibly manufacturing them for actual sale.

By doing these continuous developments to the TRIZ-based education syllabus, the evaluation of the projects can be validated further. Students are also exposed to a more comprehensive process of developing actual products which can be potential innovations. Above all, the students would have the early opportunity to sharpen their TRIZ-based problem-solving skills even before entering the industry.

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THE INTEGRATION OF TRIZ AND SCAMPER FOR A MORE COMPREHENSIVE INNOVATIVE APPROACH

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Abstract

SCAMPER is a checklist method for creative thinking. It has seven steps which include substitute, combine, adapt, modify, put to other uses, eliminate and rearrange. Although it give a whole map for innovation activities from the macro view, there is a lack of detail approach in each step. TRIZ provides a set of tools which give more structure paths how to reach creative thinking. However, leaners always give up due to the difficulties at beginning. Therefore, this study derives the advantages of SCAMPER and TRIZ, and provides a comprehensive innovation model.

Keywords: SCAMPER, 9 Window, Function, 40 Inventive Principles, Su-field Model

1. Introduction

Innovation is crucial for industry development and driving force to solve problems and advance. Creativity plays an important role as an individual's growth and development, especially on the development of civilization. Those who fail to innovate can only get engaged in low-value work as they are lack of competitiveness.

Not a few creative thinking strategies have been developed over the past several decades in education and business circles, wherein, the five most commonly used creative thinking strategies in primary and middle schools are Mind Mapping, SCAMPER Method, Mandala Thinking Techniques, Six Thinking Hats, and Brainstorming which was the results jointly achieved by Chao-I Chen and his graduate students (who were also teach excellent student class) by collecting data and discussion in the research of "Special Study on Creativity" at Graduate School, Department of Special Education, National Taiwan Normal University [Chen et al., 2010]. After study and exploration, this study adopted SCAMPER Method as it was easier to integrate with TRIZ.

2. Literature Review

Systematic innovation is a science promoting the advancement of technology and society which is designated to help average people to solve problems in a systematic and creative manner through systematic methods. Here are some theories of systemic innovation:

2.1 SCAMPER

SCAMPER is one of the most common creative skills, which was first applied to the improvement of product or items. It is the summary of seven major methods. Along with the rapid economic development, SCAMPER has been used in many different sectors and become one of the vital methods of innovative thinking in modern times. It is often used to improve existing products, services, or business models. Its predecessor was the Check List Method of Alex Osborn which contained a total of 75 questions classified into 9 categories to induce creative ideas. Bob Eberle later summarized them into seven categories. And the word " SCAMPER " refers to the first letter of the seven categories, namely, Substitute, Combine, Adapt, Modify, Put to other uses, Eliminate, and Rearrange which are helpful to check the possibility to adjust the current status and have new ideas. It offers good ideas and diversified possibilities for creation, especially in improving existing products and matters.

2.2 TRIZ Theory

Altshuller (1946), a Soviet patent researcher, analyzed patent documents and summed up the basic issues and solving skills of a variety of innovation to propose solutions to address problems in different periods and fields, and proposed TRIZ.

TRIZ was adopted to study the innovation methods of previous studies and the nature which were summarized into a science. The principles and methods of the science are employed to solve problems in a systematic and creative manner. The principles in previous invention were extracted and grouped into general rules to point out the direction of thinking to solve problems in the future [Clausing, 2001; Sung, 2009; Chao et al., 2010].

2.3 9-windows analysis

Past, Present, and Future were correlated to Super System, System, and Subsystem of the system (surrounding environment, the system itself, and the constituent elements of the system), which was adopted to analyze possible questions. 9-windows analysis adopted logical deduction to think about the available things (resources) around, break psychological inertia, and use untapped resources to solve problems. It contains two tables, namely life cycle (various stages of a product from raw material acquisition, production, application, maintenance, and disposal) and trend (products of different generations) [Sung, 2009]. It can be applied by following below steps:

Step 1: Draw 9-windows and the corresponding system operators with Super System on top, System in the middle, and Sub System in the bottom. The fields of the left are Past, Present, and Future.
Step 2: Position yourself in the 9 windows and start thinking from Present.
Step 3: Identify available resources through the connection relationship (e.g.: the relationship between System and Subsystem) of each two adjacent cells sequentially. The so-called resources refers to all the things existing in the surrounding environment and untapped. Usually, there are six aspects (i.e.: field, substance, space, time, function, and information).
Step 4: List all of the resources to eliminate "harmful effect" and improve ideality.
Step 5: List all of the resources to enhance "useful effect" and improve ideality.
Step 6: Repeat steps 2 to 5.
Step 7: Analyze directions of possible solutions.

2.4 Function

Function refers to the action (provider of function, tool) by a substance on another substance (receiver of function, subject), which is used to change or maintain the attributes/parameters of the substance (receiver of function, subject) [Ikovenko, 2010], as shown in Figure 1.

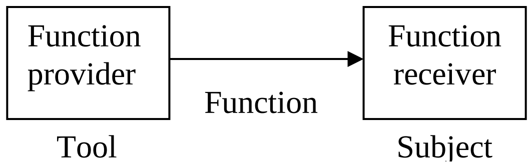

Figure 1 Analysis diagram of function - definition

All the actions which can produce changes are functional. Two ways are used to describe this relationship, namely, SAO (Subject, Action, and Object) and SVO (Subject, Verb, and Object). Function means a type of ability which can change or maintain certain parameter. For instance, "temperature" is a parameter/attribute whose value shows the number of degrees.

If a microwave is used to have a test question of function, "what action does a microwave do?" Answer: "Heating." A microwave changes the parameter of "temperature" of food [Sung, 2012].

2.5 Ideality

The guidelines to assess ideality: It shall correspond to existing products with similar functions. (1) All the original "harmful effects" are gone. (2) New "harmful effects" have not appeared. (3) All the "useful effects" are maintained, while new ones are discovered. (4) All the trade-offs and conflicts of the problems are removed. (5) Previously negligible, unused, and readily available resources are used. (6) The system does not become more complex. (7) Other system-related needs (safety, regulation, easy production, and so on) are met [Sung, 2009].

3. Research method

3.1 SCAMPER

The 7 letters of the word "SCAMPER " refers to the starting points of 7 innovative approaches which are described as follows:

(1)S = Substitute = Is there a new function or material which can replace the original?
(2)C = Combine = What functions can be integrated with the original functions? How to integrate and use?
(3)A = Adapt = Can the original material, function, or appearance be adapted slightly?
(4)M = Magnify/Modify = Can the original material, function, or appearance be magnified or modified?
(5)P = Put to other uses = In addition to existing functions, are there any other uses?
(6)E = Eliminate (eliminate) = What functions can be eliminated? What materials can be reduced?
(7)R = Re-arrange = Can the sequence be re-arranged?

3.2 SCAMPER steps

The five steps of traditional SCAMPER:

Step1: The starting points of innovation: Make a table with 6 columns and 8 rows and list 7 starting points of innovation
Step2: Definition: Identify the definition of the most suitable subjects for the application of each starting point
Step3: Question: Ask questions based on the starting points
Step4: Answer: Provide several possible solutions to the questions
Step5: Assessment: Assess the feasibility of the solutions and choose the most appropriate one to improve processes or products

Table 1

Checklist of traditional SCAMPER

No. & Aspects	Starting Points of Innovation	(1) Definition	(2) Questions	(3) Answers	(4) Assessment
1. Substitute	What is replaced? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.	Starting point (S) applied to the definition of subjects	Ask the questions based on the starting point	Provide several possible solutions to the questions	Assess the feasibility of the solutions and choose the most appropriate one.
2. Combine	What can be integrated with? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				
3. Adapt	What shall be adapted? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				
4. Modify	Change characteristics? Meaning? Size? Sound? Time? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				
5. Put to other uses	Are there any other new uses? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				
6. Eliminate	Make the original object smaller? More concentrated? Omit certain details? Make it more complete and refined? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				
7. Re-arrange	Regroup? Reorder? Switch positions? Roles? Part? Function? Shape, color, quality, material, people, objects, time, things... etc.				

3.3 The implementation of SCAMPER integrated with TRIZ

The fourth step of the five steps of SCAMPER aforementioned--Think about possible solutions and generate creative ideas based on the starting points of each questions--is the key of this process. This study combined 7 starting points in the 9-windows of function and ideality of TRIZ to generate creative ideas.

The starting point of Subsystem in the 9-windows was constituent elements. Functions were directly listed in the table. For ideality, the advantages and disadvantages before and after certain creation were compared comprehensively to see if the increase of advantages was more than that of disadvantages then make decisions. If the increase of advantages was more than that of disadvantages, ideality would be higher, and vice versa. If ideality was enhanced, the replacement should be done. Then, each of the 7 innovative approaches of SCAMPER was shown by tables respectively, table 2-8. Each approach includes items such as composition, usage scenarios, function, subject, problems found, analysis of problem and cause, application of each innovative approach (e.g.: replacement, combination), original advantages, original disadvantages, new functions, new advantages, new disadvantages, and comprehensive comparison. Tables of combination and put to other uses are described later due to other consideration.

(1)S = Substitute
The table of Substitute of this study is as shown in Table 2.

Table 2

Substitute

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Usage scenario		
3 Function		
4 Subject		
5 Substitute things		
6 Analysis of problems and causes		
7 Replacement		
8 Original advantages		
9 Original disadvantages		
10 New functions		
11 New advantages		
12 New disadvantages		
13 Comprehensive comparison		

(2)C = Combine
Combination involves two or more goods or services. It is common to combine with surrounding objects, thus the table of Combination has one more item of "surrounding objects".

Table 3

Combine

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 Needs found		
5 Effects required		
6 Surrounding objects		
7 Combine things		
8 Original advantages		
9 Original disadvantages		
10 New functions		
11 New advantages		
12 New disadvantages		
13 Comprehensive comparison		

(3)A = Adapt

Table 4

Adapt

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 Problems found		
5 Analysis of problems and causes		
6 Adapt things		
7 Parameters for adaption		
8 Original advantages		
9 Original disadvantages		
10 New functions		
11 New advantages		
12 New disadvantages		
13 Comprehensive comparison		

(4)M = Modify

Table 5

Modify

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 Problems found		
5 Analysis of problems and causes		
6 Modify things		
7 Original advantages		
8 Original disadvantages		
9 New functions		
10 New advantages		
11 New disadvantages		
12 Comprehensive comparison		

(5)P = Put to other uses

As it is necessary to identify the demands of other fields of application, generate the application in other fields, and involves different subjects and fields, the table of put to other uses has "new demands" and "new subjects".

Table 6

Put to other uses

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 New demands found		
5 Effects required		
6 New subjects		
7 Original advantages		
8 Original disadvantages		
9 New functions		
10 New advantages		
11 New disadvantages		
12 Comprehensive comparison		

(6)E = Eliminate

Table 7

Eliminate

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 Problems found		
5 Analysis of problems and causes		
6 Things to be eliminated		
7 Function of the eliminated?		
8 Original advantages		
9 Original disadvantages		
10 New functions		
11 New advantages		
12 New disadvantages		
13 Comprehensive comparison		

(7)R = Re-arrange

Table 8

Re-arrange

Item	a. Technique	b. Service
1 Composition	Components	Element
2 Function		
3 Subject		
4 Problems found		
5 Analysis of problems and causes		
6 Things to be re-arranged		
7 Original advantages		
8 Original disadvantages		
9 New functions		
10 New advantages		
11 New disadvantages		
12 Comprehensive comparison		

3.4 The instances of implementation of SCAMPER integrated with TRIZ

To help readers understand how SCAMPER integrated with TRIZ generates creative ideas, the author provided instances for each table for readers' reference and better comprehension.

Table 9

Substitute (Correction fluid, Cleaning)

Item	a. Technique	b. Service
Theme	Correction Fluid	Cleaning
1 Composition	Correction liquid, container, cover	People, broom, dustpan
2 Usage scenario	Writing mistake	Sweep the floor
3 Function	Cover the wrong word and rewrite	Clean up dust and garbage on the floor
4 Subject	Wrong word	floor
5 Substitute things	Toxic gases emitted. Rewrite after the liquid dries.	More money is spent by hiring people to clean, but more time spent by cleaning by oneself.
6 Analysis of problems and causes	Correction fluid contains toxic methyl cyclohexane	Not enough own money and time
7 Replacement	(Mainly) replace the fluid with a solid body	Human (replaced by a cleaning robot)
8 Original advantages	Details can be modified	It is cleaner after more careful sweeping.
9 Original disadvantages	Toxic gases emitted. Rewrite after the liquid dries.	Time- and effort-consuming
10 New functions	Rewrite immediately on flatter surface	Auto-cleaning
11 New advantages	No toxic gases. Rewrite immediately on flatter surface	Save time and efforts
12 New disadvantages	Cannot modify details	Corners cannot be cleaned
13 Comprehensive comparison	Health is important. No need to wait.	Save time and efforts

Table 10

Combine (Sneaker, Shopping)

Item	a. Technique	b. Service
Theme	Sneaker	Shopping
1 Composition	Shoe sole, vamp, lace	Buyer, goods, shops, attendant
2 Function	Sports	Shopping
3 Subject	Feet	Goods
4 Needs found	Need to move fast sometimes	Not enough time to go shopping in shops
5 Effects required	Reduce the force of friction between shoe soles and the ground	Buy things without going to a shop
6 Surrounding objects	Ground, feet, wheels	Computer, Internet, credit card, ATM
7 Combine things	Shoe sole, wheel (Wheels attached to shoe soles can reduce the force of friction with the ground.)	Goods, shops, Internet
8 Original advantages	Stable	See and touch on spot
9 Original disadvantages	Cannot move fast	Time-consuming
10 New functions	Move	Save time, one-stop shopping

11 New advantages	Move fast	No need to go out. Compare prices faster
12 New disadvantages	Not stable	Harmful to eyes, consumes electricity
13 Comprehensive comparison	Need to move fast in some places (skating rink)	Convenient, timesaving, indoor

Table 11

Adaption (Chair, Car wash by a robot)

Item	a. Technique	b. Service
Theme	Chair	Car wash by a robot
1 Composition	Chair legs, seat, back	Cleanser essence, brush, robot
2 Function	Support	Clean
3 Subject	Human (bottom)	Car
4 Problems found	Feet cannot reach the ground. Being uncomfortable after sitting for a long time.	The inside of the car is still not clean after car wash.
5 Analysis of problems and causes	The lengths of the legs of each person are different.	Robot car wash only washes the outside of a car
6 Adapt things	Chair legs	Areas to be cleaned
7 Parameters for adaption	Height	Cleaning time and area
8 Original advantages	Simple structure, cheap	Clean appearance
9 Original disadvantages	Not suitable for the lengths of legs	The inside is not clean
10 New functions	Change height	Clean the inside
11 New advantages	Suitable for the lengths of legs of each person	The inside is cleaner
12 New disadvantages	Complex structure, more expensive	Spend more money and time
13 Comprehensive comparison	High-class location/sitting for a long time can use adjustable chairs as they are more comfortable.	The inside of a car is cleaner and neater.

Table 12

Modify (Tungsten wire bulb flashlight, Fuel up)

Item	a. Technique	b. Service
Theme	Tungsten wire bulb flashlight	Fuel up
1 Composition	Tungsten wire bulb, battery, flashlight	People, gas, car
2 Function	Illumination	Fuel up
3 Subject	Object, environment	Car
4 Problems found	Consume electricity, not bright enough	The car is not clean enough
5 Analysis of problems and causes	Tungsten wire is heated to about 2500℃ to produce light by heat radiation, so it consumes more electricity.	Not enough time to have a car washed
6 Modify things	Change a bulb to an LED	Fuel up with car wash service
7 Original advantages	Simple and cheap unit price	Fast and timesaving
8 Original disadvantages	Consume electricity, not bright enough	No value-added service
9 New functions	Same brightness	Car wash
10 New advantages	Brighter, save more electricity	Cleaner car

11 New disadvantages	Higher unit price	Time-consuming
12 Comprehensive comparison	Total expense is cheaper for long	Cleaner car, car wash cost saved

Table 13

Put to other uses (Tire, Social security maintenance)

Item	a. Technique	b. Service
Theme	Tire	Maintain social security
1 Composition	Rubber	Police, equipment
2 Function	Protect wheel rims (wheel function: move a car)	Fight against crimes
3 Subject	Wheel rims (subject of wheels: vehicle - goods)	Crimes
4 New demands found	Appreciation	Serve the people (find dementia seniors), prevent crimes (safety for those who withdraw vast sums)
5 Effects required	Reshape	Execution, fighting capacity
6 New subjects	Human (audience)	Dementia seniors, those who withdraw vast sums
7 Original advantages	convenient production	simple task (maintain social security)
8 Original disadvantages	Low price	Many jobs do not have appropriate worker
9 New functions	Artistic appreciation	Assist in finding the senior, protect vast sums
10 New advantages	High price	Safer and more harmonious society
11 New disadvantages	Time-consuming production	Heavier load of police
12 Comprehensive comparison	High price of artwork	It is worth promoting a safer and more harmonious society

Table 14

Eliminate (Electric fan, Road toll)

Item	a. Technique	b. Service
Theme	Electric fan	Road toll
1 Composition	Engine, leaf, gear	Toll collector, receipt, ticket book, car
2 Function	Move the air to make one feel cool	Charge
3 Subject	Air	Car owner (driver)
4 Problems found	A child may get hurt by touching the leaves	Speed is lowered at a toll station
5 Analysis of problems and causes	The leaves need to move fast to move the air with great force, so kids may get hurt by touching them	Drivers need to stop their cars to get ticket book at manual toll station resulting in a long queue sometimes
6 Things to be eliminated	Leaves	Toll station, toll collector
7 Function of the eliminated?	Move the air	Manual toll collection
8 Original advantages	Cheap	Give change
9 Original disadvantages	A child may get hurt by touching the leaves	Time-consuming
10 New functions	Bernoulli's Law is adopted to replace the necessity to move the air	A device (e-Tag) is used to replace manual toll collection
11 New advantages	Safe	Save time and efforts
12 New disadvantages	High cost	Mistakes occur if the system is not perfect. Unemployment

13 Comprehensive comparison	Safety of kids is important. It is worth of it.	It is worth of promoting as it is timesaving and environmental friendly.

Table 15

Re-arrange (CD container, Ordering at fast food restaurants)

Item	a. Technique	b. Service
Theme	CD container	Ordering at fast food restaurants
1 Composition	Wallboard, nails	Main meal, side order, beverage
2 Function	Collect CDs	Provide food & beverage
3 Subject	CDs	Consumer
4 Problems found	CDs are not clearly classified	Long time in queue and ordering
5 Analysis of problems and causes	Each drawer cannot be shifted	Time-consuming to order main meal, side order, and beverage one by one
6 Things to be re-arranged	Connection of the top and lower layers	Main meal, side order, and beverage (re-arranged into packages)
7 Original advantages	Stable	Main meal, side order, and beverage can be ordered one by one according to individual preference.
8 Original disadvantages	Not flexible	Time-consuming
9 New functions	Classify	Faster
10 New advantages	Clear classification	Pre-set package includes main meal, side order, and beverage and requires ordering once.
11 New disadvantages	Increase materials and costs	Main meal, side order, and beverage cannot be ordered one by one according to individual preference.
12 Comprehensive comparison	Classification is more convenient	Meet many consumers' needs faster

4. Discussion and Conclusion

SCAMPER is a common creative skill used to improve existing products, services, or business models. Based on the five steps of traditional SCAMPER, this study proposed a SCAMPER checklist combined with TRIZ 9-windows with function and ideality as its core, which emphasized practicability more.

The tables were introduced during the classrooms of the author. It has been found that with the tables, students can consider more about practicability more during creation, so they are worth of application. The tables were also explained during the internal training to a gasket seal company in Wurih, Taichung, followed by a Thank-you Letter. The company extended its gratitude to the contribution brought about to its R&D via the method. Based on the above industrial-academia support, this SCAMPER checklist is published for the reference of more people so that they can adapt it to meet their locations or fields.

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TREND OF INCREASED ADDRESSING OF HUMAN SENSES - Focus on Sound -

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Abstract

One of the key results of Gendrich Altshuller's research is the definition of Trends of Engineering Systems Evolution (TESE). These Trends have proved their correctness over decades in the technical and nontechnical environment.

This paper suggests adding another viewpoint to the Trends by not only considering the development of technical system themselves in a technical environment, but by focusing on the interaction of a technical system with users and the thereof resulting requirements and development directions. It is an application of the Trend of system coordination.

The focus of Engineering System Evolution (TESE) is engineering systems. Nevertheless, engineering systems do not exist for their own purpose. Eventually they address human beings and serve them (the one way or the other).

Following this view the human being is the super system and even the target for the engineering system. The interaction between both is done by the senses of the human being. Following the trend of "transitioning to the super-system", engineering systems will include the human being or at least his senses.

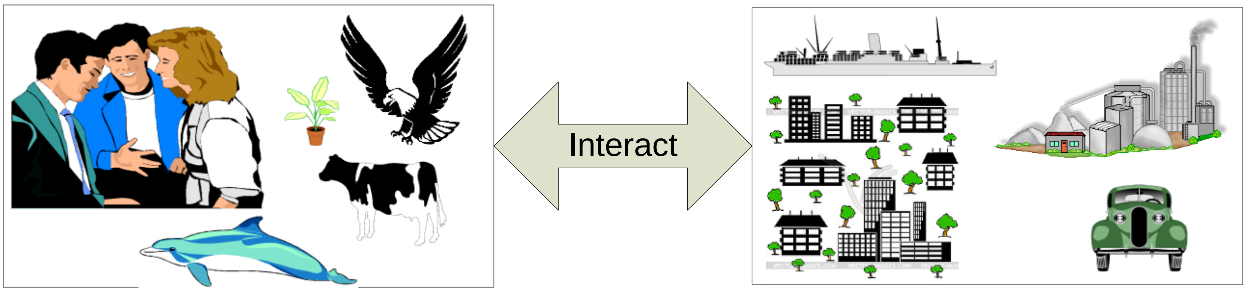
Alexander Lyubomirskiy has shown in his research that there is a trend of "Coordination of images". This trend is focusing on only the visual sense of a human being. This study suggests expanding this approach to all human senses, auditory, kinesthetic, gustatory and olfactory. With this the complete human interface towards technology and the world is addressed.

This paper discusses the systematic approach to this evolution. It will display the human senses and relate to supplementary senses for animals. The way that technical systems are constructed to impact the senses and the evolution over time on how this is done with technical systems will be shown. Finally the usage of other trends (e.g. dynamization) to focus the impact of the technical system to the human senses will be discussed. The final point will be the development of technical systems to address several senses at the same time.

Keywords: TRIZ, Trend analysis, Trend of increased coordination, human senses.

Interactions

The world can be divided into two parts: animated organisms (human beings, animals, bacteria, etc.) and unanimated materials (earth, rocks, bricks, technical systems, etc.). Both parts co-exist in the same environment and influence each other.



Interaction of the two parts on our planet: animated / unanimated materials
(CorelDRAW! Cliparts, 1993)

The interaction between both systems is based on the sensory / input channels of both parts. For unanimated parts this generally is the material surface (defined on the atomic level). Nevertheless, there are of course fields that may interact on deeper levels as well. For animated parts it is the sensors that are available. Human beings generally have 5 types of senses [1, 18]. Science is discussing if there are more, but for this research we focus on the confirmed ones:

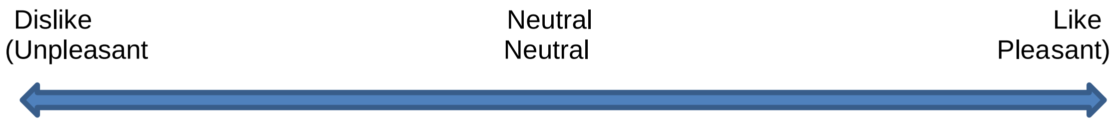
- Seeing (visual) – distance sensing
- Hearing (acoustic) – distance sensing
- Sensing (touching), which may be separated into 3 separate aspects: touching, temperature, pain – nearby sensing
- Tasting (chemical) – nearby sensing
- Smelling (chemical) – nearby sensing

When expanding this analysis to other living units we find lots of supplementary sensors [2]:

- Bats use sonar
- Snakes use infrared light
- Bees and fishes can see UV radiation
- Fish use branch-line-organs for detection of water flow direction
- Electric eel can detect electrical fields
- Birds have sensors for magnetic fields and UV radiation
- Turtles detect the pH-value of water
- Spiders and scorpions detect vibrations
- etc.

Classification of interactions

Humans usually classify their sensoric input into the following simplified model:



All of the information supplied by one or several of the senses is interpreted based on past experiences within a range from “like (pleasant)” to “dislike (unpleasant)”.

With the decision “like (pleasant) / dislike (unpleasant)”, living creatures direct their activities to the feeling layer. The other decision layer is the logical, cognitive decision process. It relies on countable and measureable arguments.

The most important trend is convergence to ideality. Technical systems aim at self-fulfillment of their functions. However technical systems do not exist on their own and for themselves. They are always, maybe via other technical systems, linked to human beings (living creatures). The final receiver of the functionality will be a person in the end.

In the real world an industry has been developed for the following purpose: marketing, design and advertising. In the last few years a discipline called neuro-marketing has evolved [3]. The idea is to use neuroscience to better understand customer psychology and behavior in the dislike (unpleasant) / like (pleasant) sense. Research has shown that human beings react on information they get through their senses with emotions and feelings. Emotions are neutral and represent a bodily response to inner and outer events. An example is starting to sweat when temperature is rising. Feelings reflect the conscious experience of being in a particular emotional state. This means that there can be emotional responses without feeling, but you cannot have feelings without accompanying emotion [3]. This leads to the relation of wanting and appreciation. An example is the choice of eating chocolate while on a diet. You feel the urge for a snack and the sugar boost, but consciously think it's a bad thing to do. Wanting is an unconscious aspect, appreciation is a conscious experience. And the conscious aspect is the one that can be influenced.

According to the above statements, a person allocates his environment and the information he obtains about it via his senses to categories dislike (unpleasant) – neutral – like (pleasant). Of course the binning is dependent on region, culture, experience and learning in life in general. Still the environmental perception will be categorized. Therefore the technical ideality a system is striving for has to be taken into consideration for the human binning process as well.

A particular branch, sensory neuromarketing, is emerging, focusing on how sensory inputs other than visual and hearing can influence decisions (like smell of fresh bred close to bakery). So also neuromarketing is developing in the direction of involving more senses contemporarily.

There are studies regarding Multisensory Integration, which describes a process by which information from different sensory systems is combined to influence perception, decisions, and overt behavior.

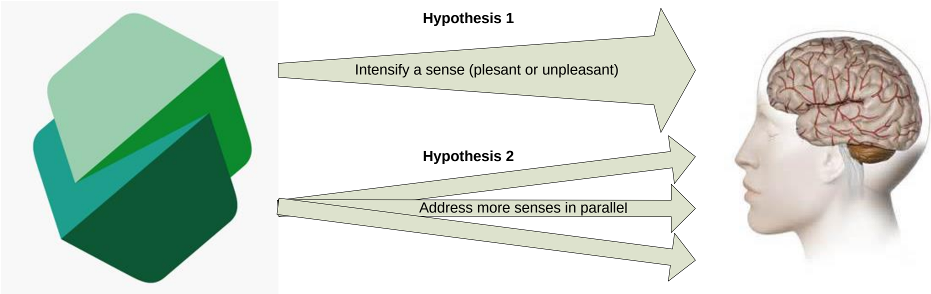
Hyposthesis

TESE concentrates on the technical evolution of components, which reflects the logical side of the decision making process. The first hypothesis is that components too evolve towards emotional ideality in terms of generating a “like” (pleasant) feeling or, in case of warning, a “dislike” (unpleasant) feeling. The second hypothesis is that components evolve from addressing only one sense towards addressing multiple senses. This is another view of the Trend of system coordination.

Hypothesis 1 focusses on improving the functionality of the component. Relating this to the S-curve development, this strategy may be used in the 1st and 2nd stage.

Hypothesis 2 focusses on intensifying the number of senses addressed. Here the technical functionality of the component is more or less ideal and there is a shift towards the emotional impact. This is applicable to components in the 3rd and 4th stage of the S-curve.

The defined hypothesis shows trends of the evolution of the components per se. Of course a manipulation by conscious combination of senses addressed or by inverting an unpleasant feeling to a pleasant one or vice versa is possible and even probable in business applications. These methods of applying of a trend to influence conscious and unconscious senses will be discussed later in this paper.



Observations

The hypothesis that components / systems evolve towards emotional ideality is hard to prove as there is no “old emotion” that can be conserved in an objective way. Therefore as a first indicator we will look at the different human senses and how they affect our brain / thinking and how they were stimulated in the past.

Principle function of our brain

The human sensors are connected to our brain where data evaluation is performed. The principle set-up of our brain functionality is shown in the following figure. It is basically divided into 2 parts: left and right. The right side is designed for our more creative, chaotic and unconscious capabilities. The left side represents our logic, number-oriented, systematic and conscious capabilities. Both sides are connected and interact.

Brain functionalities: left side “logic”, right side “creativity”

Neuroscience has shown that the right side as the unconscious side is operating ~ 100 times faster in data processing than the left side of our brain (the conscious part) [4]. This fast operation generates the “guts feeling” very fast but lacks the reasoning where this feeling is coming from. The left side needs much more time to generate the same result, but in this case the process of reaching the result is conscious.

Our sensors are attached with some preference to the different sides of the brain. Our distance senses (seeing, hearing) are related more to the left side (conscious, “logic” part) and the senses of sensing, tasting and smelling while the near senses are related more the right side (unconscious). This has an evolutionary background. If a danger was registered nearby by our senses an intermediate reaction was needed. There was no time for an extensive evaluation by our slow left brain side. Our distance senses offered more time for a reaction and are therefore connected to the left side for a conscious and learning experience.

Psychology has shown that usually a person has a preferred side, dominating his characteristics and behavior [4]. According to the Trend of Engineering System Evolution (TESE) the system “brain” tends to bring both sides together as an equivalent system [3]. This is especially true for today's time, where only very little sudden danger occurs in our life (unless you cross a traffic road with closed eyes).

Main Human Sense Seeing (visual)

Looking back into history people were not very much interested in "how good something looks" except for religious artefacts and paintings. Churches, mosques, temples were constructed to be higher, brighter, more valuable, prestigious, etc. Evolution always went in the direction of "more impressing". With industrialization the design of components got more and more important besides the pure functionality. Today a product has to be designed, even in an industrial environment. At least colors have to look appealing for a component and this is getting more and more a decision criteria for users and customers. Looking at a car advertisement in the 1960s was all about technical features: engine size, speed, acceleration, volume of the trunk, etc. Today it is about the feeling:

1960 2014

Car advertisement past and today (magazine.volkswagen.de; bmwusa.com)

Another area is fashion. The functionality of clothes today is taken for granted. It distinguishes from the felt appearance: Does it "look good"? Since the functional evolution, fashion has concentrated on feelings. Usually the visual sense is more related to the left sector of the brain and thus refers more to conscious influence. Information is taken and consciously analyzed for the decision of pleasant / unpleasant [1].

Another aspect is the function „inform people". People wearing luxury objects inform other people on the economical / social status of the owner or belonging to a certain group or subculture.

Also Apple works with their products a lot on visual for the same reasons and in addition, the visual interface is perceived as more intuitive since the brain is a strong visualizer.

Main Human Sense Hearing (auditory)

The evolution of sound found its direction in music. Components are allocated with sound that makes you feel good and generates a pleasant feeling. You can see this with cars: the sound of an engine has to correspond to its perception of delivering power and speed. The German Railway made a survey to find out in which train people feel safest. It was in trains with a dedicated locomotive that made a lot of sonorous noise (from the cooling fans) – the feeling of power – instead of a bee's sound from distributed drives. Sounds are designed today to generate different feeling: sirens for emergency vehicles to generate awareness (using the unpleasant aspect of these sounds – loudness and yelling type), background music in shops to open the emotional channel of customers (and retain them inside), etc. Usually the auditory sense, too, is more related to the left sector of the brain and thus refers more to conscious influence. Information is taken and consciously analyzed for the decision of pleasant / unpleasant [1]. So the two dominating senses (seeing and hearing) are related to our conscious perception.

Main Human Sense Sensing (kinesthetic)

One of the tools we are mostly using unconsciously is sensing. When judging a component we often take it into hands, touch it, feel the surface, its density, humidity, weight, etc. This can mostly be observed in food shops. We take the product into our hands. We look at it and touch the packaging to get a feeling. This is essential for the final purchase decision. Usually the sensing sense is more related to the left sector of the brain and thus refers more to the unconscious influence. Information is processed within milliseconds and generates a response of pleasant / unpleasant [1]. Touching something too hot or hurting is a direct threat to our body. And this threat is very near. Therefore our body produces an unconscious direct reaction for protection purposes. Visual and auditory senses are more distance related and therefore can afford to bypass the conscious mind, which takes longer for data processing, but allows more fine-tuned response.

Touching, feeling the product with our sensing sensor (sueddeutsche.de)

Main Human Sense Tasting (gustatory)

Babies and kids test their environment by trying out how it tastes: can it be “eaten”. Food as the essential product to be tasted has also undergone a development. In former time food was seen as energy provider with only little variation from day to day. Today taste is designed into products. Flavor enhancers are used to generate a certain taste. The best examples are burger chains where the food offered tastes the same all over the world (convenient food). Usually the sensing sense is more related to the left sector of the brain and thus refers more to unconscious influence. This is due to the fact that bad food can be life-threatening and is identified by the taste. The reaction to bad food has to be immediate and therefore is unconscious.

Kids test their components by tasting (mytoys.de)

Main Human Sense Smelling (olfactory)

Smell has the most direct impact on the brain [1]. In contrast to the other senses the brain allocates a feeling to smelling right away. This feeling without the detour via emotions is based on the history of experience of a person. So it can be that a smell that somebody likes a lot and considers pleasant (like) can be ugly for another person and generate a dislike (unpleasant) feeling.

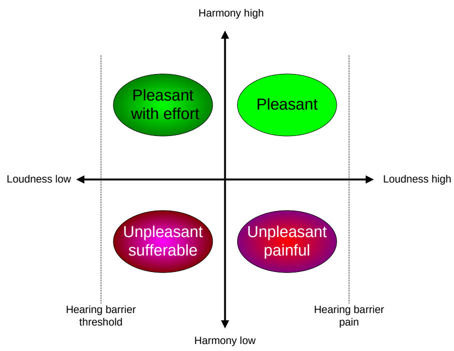
Allocation of smell to a product – emotionally (weingeruch.de)

Smelling works in a similar way as tasting. It has a direct impact and therefore is unconscious as well.

Evolution Directions of the Hearing / acoustic / auditory Sense

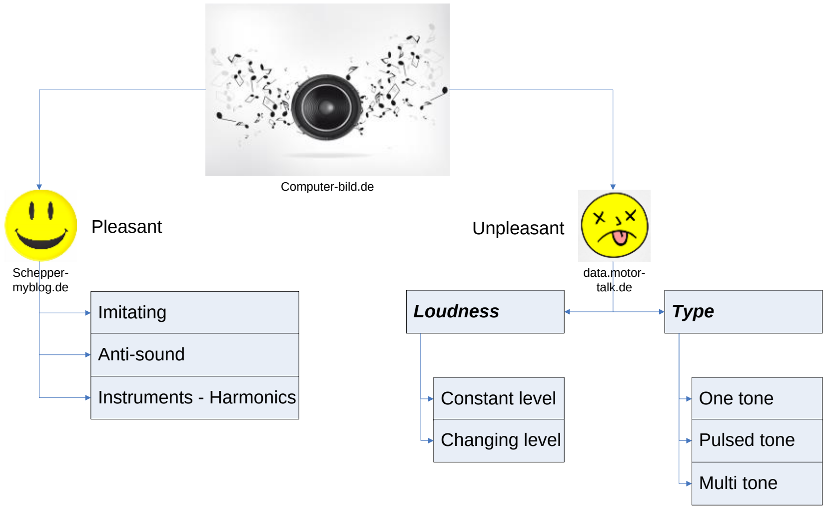
This chapter will focus just on the acoustic sense as example. I will lay out how the sense itself can be influenced and how the influence can be intensified. Examples in nature and technology will be displayed.

Alexander Lyubomirskiy from Gen3Partners conducted deep research on trend for "coordination of images" which reflects a set of measures and principles to increase or decrease visibility in general. This is in very close relation to the major sense of the human being: "seeing (visual)". One can leverage this methodology to hearing (auditory), sensing (kinesthetic), tasting (gustatory) and smelling (olfactory), which will be done in the next steps. At the end a combination of the coordination of the senses will summarize the trend to satisfy human senses.



Two basic parameters for hearing

Hearing or, more generalized, sound detection is a sense that is allocated to the ears. It can be rated by two parameters: Loudness and Harmony



Structuring of sounds

Sound in its basic form is a sine wave. With a single wave at a defined frequency the loudness can be experienced. It starts at the hearing threshold and stops at the pain barrier where the loudness starts to hurt.

Starting from the basics of sound (loudness and harmony), they can develop into different directions. The major separation, in relation to the coordination of images, can be done by separating pleasant and unpleasant sounds.

In real life a sound is always composed of a superposition of sine wave. Here human beings have an affinity to a composition of the sound. It has to follow mathematical rules in order to express harmony and to generate a “good feeling”. In music, harmony is the use of simultaneous pitches (tones, notes), or chords. The study of harmony involves chords and their construction and chord progressions and the principles of connection that govern them. Harmony is often said to refer to the "vertical" aspect of music, as distinguished from melodic line, or the "horizontal" aspect. Harmony usually generates a “comfortable feeling” and disharmony an “uncomfortable feeling”. A harmonic sound with the right loudness is pleasant. If it is too silent it is pleasant but with effort as one has to concentrate to get it. A disharmonic sound at low loudness is unpleasant but bearable. If it is too loud it becomes a painful experience.

Pleasant sounds

In the category of pleasant sound we find imitating sound, anti-sound and instruments.

Imitating sounds

Imitating sound is often found in nature where e.g. one type of animal copies the sound of another species in order to warn enemies although they do not possess the features of the original species. Examples of imitation are:

- The starling imitates the oriole. Orioles are birds that stay mainly on their own. A starling therefore imitates its sound in order to chase away the rival when it comes to secure bird’s nest area.
- The black earth colubrid. She imitates the sound of a rattlesnake to protect herself.
- A ventriloquist imitates the voice of another person.
- The real sound of an airplane is imitated in a remote-control model.
- Playback in music shows is another way of imitation.

In technical system imitation is used e.g. for burglar protection. Electronic devices imitate the sound of dogs to prevent intrusion into homes.

Anti-sound

Anti-sound or sound cancellation is used in technology to dampen the loudness of a sound. The principle is to generate the same sound artificially but with a phase shift of 180°. By this the waves extinguish each other. The same principle can be found with Bolus at ships. There it is not to extinguish sound but water waves in order to reduce energy consumption for ships (reduction of deformation of the water surface).

Instruments

A special effect of sound can be achieved by not only playing the base frequency of a tone, but by adding harmonics to it. This is what happens when playing a tone on an instrument (not necessarily an electronic piano that can play only the base wave as well). By this e.g. the tone takes on different colors. With different instruments playing together the super-positioning principle applies: As for an instrument the base tone is superposed with harmonics, the instruments themselves behave like harmonics.

Harmonics are a means to also express as well certain moods (like joy, melancholy, etc.) that can be used to bring people into a certain emotional condition in order to achieve desired reactions.

Unpleasant sounds

In the category of unpleasant sounds two parameters can be changed: loudness and type of signal. Generally loudness and type of signal are combined in order to achieve the attention of a person. In communication when a partner does not react, the typical reaction is to raise loudness. By this attention shall be generated. If this does not work the sound is alternated in its frequency as well. One can see this especially with kids when they cannot obtain attention from their parents.

Another field of application of unpleasant sounds is warning: fire, air-raid warning, police and emergency vehicles. In these cases the unpleasant (harmful) sounds are turned into something useful: gaining attention.

Loudness

Loudness can be set at a constant, static level or at changing levels. Human beings usually tend to adapt to constant levels as the senses are mainly reacting on changes (HNO Basiswissen). In order to generate more attention the loudness can be raised and/or lowered in steps or continuously. Good examples of this are emergency horns:

- Single-tone horn.
- Sinusoidal changing air raid warming.
- Tornado Chicago warning.

Type

Besides the loudness the type of signal can be changed. As differentiation one, several tones and pulsed tones can be used to generate an unpleasant feeling and thus create awareness. The best examples for this are fire warning devices that use trapezoidal tone changes and the sirens of police cars. Dependent of the country they have two tones (e.g. Germany), pulsed tones (e.g. United Kingdom) or a combination of loudness change, multi tones and pulsed tones (e.g. United States).

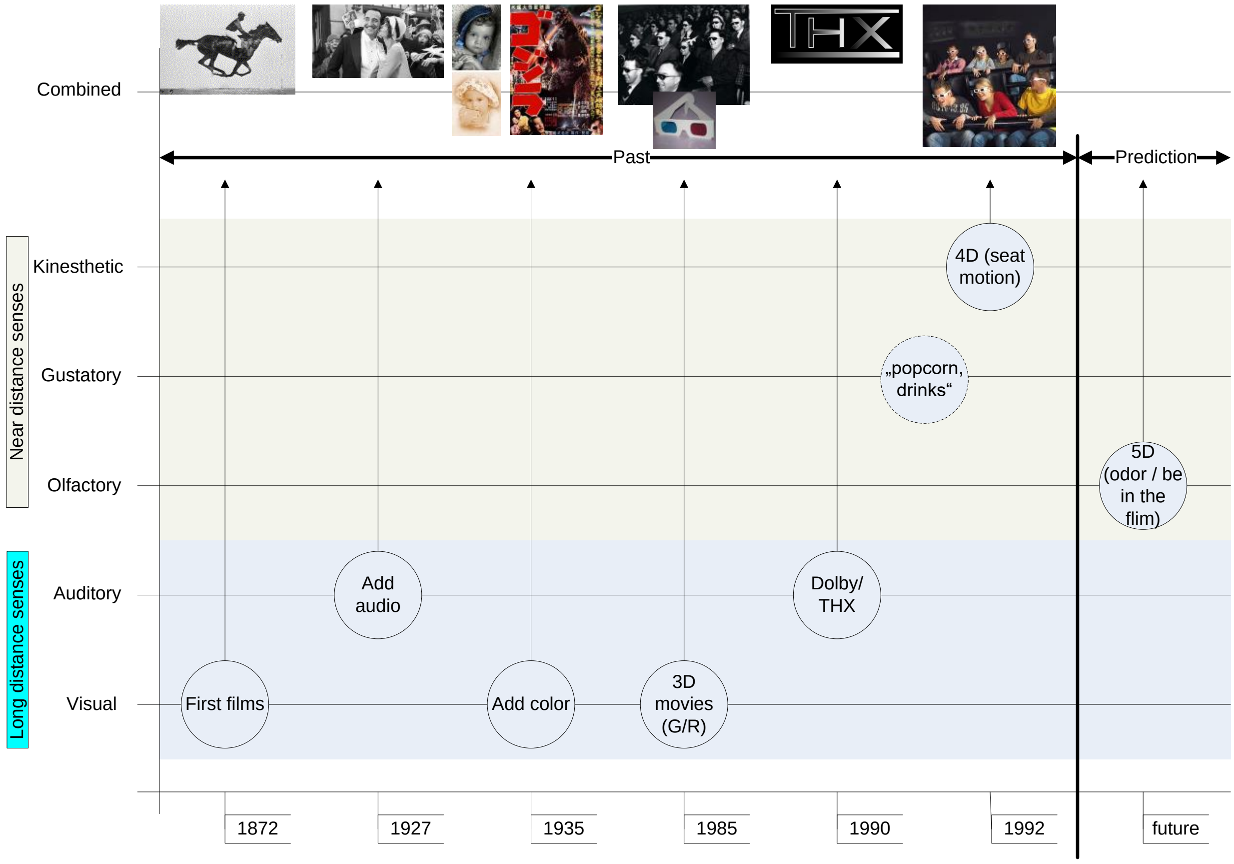
Future Outlook on application of Sounds

In the chapter before the development of sounds has been demonstrated according to its parameters. Examples of technical realizations were shown. The focus of the evaluation was on sound only to demonstrate the procedure of examination.

As a human being has at least five sense (seeing, hearing, smelling, toughing and tasting) the trend is to incorporate at the end all of them. The procedure will be:

- Add another sense
- Dynamize the sense
- etc.

As one example the development of cinema movies shall be shown.



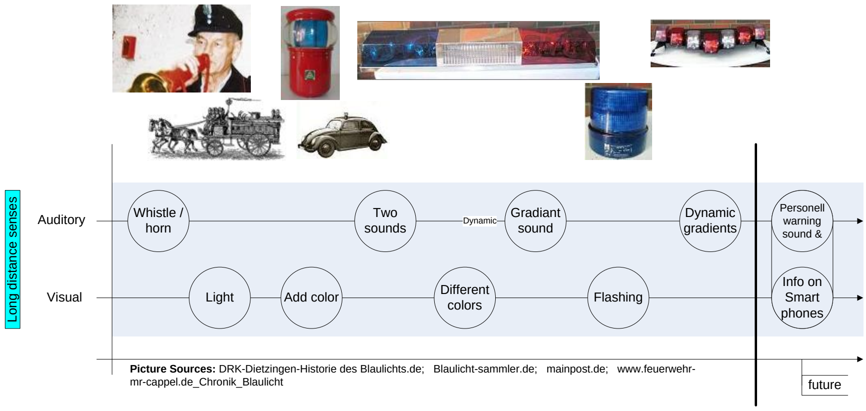
Development of cinema movies over time

Around 1872 first films (visual) are made. They are black and white, no sounds and the quality was poor. Around 1927 sounds (audio) were added and 5 years later (1935) first color films (visual) were available. 1985 3D movies were developed; but it took 15 years until 2000 to develop a better technology (polarized light instead of red/green separation) to make them accepted (visual). Around 1990 the sound was improved by moving from stereo to surround sound with noise suppression (audio). Around 1992 the first 4D movie including air steams or movable seats came (kinesthetic) on the market. In parallel selling sweets and drinks came en vogue in cinemas (gustatory), although this doesn’t have directly to do with the movie itself.

The prediction is that odor will be added to movies if corresponding ventilation systems will be available. Or chewing gums with different tastes, which correspond to the meals that are served in a movie, will be available. Another path are movies where you can interact with the plot (e.g. seeing it from different perspectives).

The auditory sense itself evolves in this example in a dynamic way: from just sound to THX. So we see the well-known trends being the basis for the umbrella trend of increased addressing of all human senses.

As development of police and their equipment is another example:



Development of police sound / light system over time

Police cars started with torch and whistles / horns. The light was turned electric and blue. Then the light was dynamized to flashing. Whistling was replaced by sound. The next step was to dynamize the sound to 2-frequency signals. Next step was to dynamize the lights with different colors (blue and red, later yellow). And the sounds were dynamized: Different loudness, different frequencies, pulsed, etc. The future might be that everybody nearby a police car gets a personalized warning sound and information on his smart phone.

Conclusiones

In the paper it was described that technical systems evolve towards addressing more and more senses of a human being. The most obvious ones are the long distance senses visual and hearing. Their development has been displayed in the paper. This trend is as well confirmed by research in neuroscience. The biological foundations of multisensory integration and its effect on human being's life and decision-making processes points in the same direction. Human-made artifacts in their evolution as engineering systems reflect the tendency to achieve an increasing involvement of the various human senses. This paper focused on hearing although similar principles are applicable be smelling, touching, tasting. This discussion will be part of another paper.

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TRENDS OF INCREASING LOCALIZATION

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Abstract

This paper is result of an attempt to develop a new sub-trend within Trends of Engineering System Evolution (TESE) - Trends of increasing localization. The objective of this paper is to showcase the potential applicability of Trends of increasing localization to different fields. This is explained by considering two case studies and a step-by-step mechanism of how this is attained at is illustrated. First case study is from the healthcare domain. The evolution of cancer treatment and the increasing level of localization made possible in cancer treatment through technological development have been studied. Second case study is from aviation industry. The development of turbine fan blade technology over the decades has been investigated and the observations on increasing localization have been reported.

Keywords: TESE, Localization, Controllability.

1. Introduction

Localization is defined as "*to fix in or confine to a definite place or* part" and "*to accumulate in or be restricted to a specific or limited area*" [1]. With technological evolution and need for faster turn-around time, dealing with issues in a localized level as compared to taking into account the entire engineering system is becoming crucial. Localization is gaining importance in multiple fields and technological segments. For example, 'software localization' is the process of adapting a software product to the linguistic, cultural and technical requirements of a target market. This process is labour-intensive and often requires a significant amount of time from the development teams. Products, be it consumer durables that last for longer durations or fast moving consumer goods (FMCGs) that consumers buy on a regular basis, have also been localized heavily to gain market ground. In this paper, through a few case studies, the authors have shown the importance of localization and how it could potentially become one of the important trends in TESE.

First is the evolution of cancer treatment. The authors show how the cancer treatment has become more and more localized with time and also evolution of newer technologies to diagnose and treat cancer.

Second is from the field of aviation gas turbines. Around 60 years back, materials used in parts of the turbine engines could not survive more than a few hundred hours at then relatively modest temperatures. As the need for fighter as well as commercial aircrafts increased over time, there was a need for improvements in engine materials. This led to development of different superalloys and composite materials for different engine components to meet the requirements of increased temperatures as well as longer flying hours. As an example, the improvements in materials technology that led to higher firing temperatures – leading to improvement in fuel efficiency is discussed. We looked at the progression of these materials to predict the trend of increasing localization. Potential areas in day-to-day life where increased localization can be seen are in areas like localized Products – marketing, product and technology strategy.

2. Methodology

Trends of Engineering Systems Evolution (TESE) are empirically derived directions of Engineering System development that describe the natural transitions of Engineering Systems from one state to another. A number of trends have been described to date and they relate to one another through a hierarchical structure as shown in Fig 1. [2]. Trend of increasing ideality is the driving force behind the development of all technologies and is a sub-trend of trend of S-curve evolution. This paper will focus on a new sub-trend called Trend of increasing localization under Trend of increasing ideality. We see that in today's fast moving and competitive world, localization of products, technologies and services are increasing. A generic product or technology for all is no more acceptable. Localization helps many organizations to compete and be successful in their non-local markets. We observe a trend of increasing localization and tried to illustrate this in a step-by-step mechanism using two examples related to healthcare industry and aerospace materials.

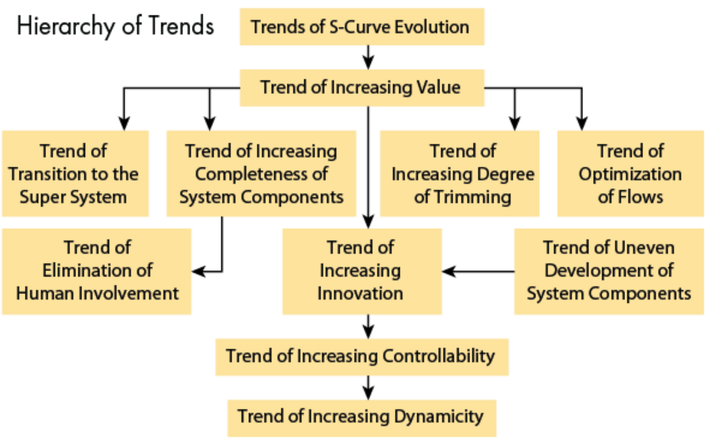

Fig. 1. Hierarchy of Trends

3. Case Studies

After skin cancer, breast cancer is the second most common cancer in women in the United States [3]. One of the earliest approaches of curing breast cancer was radical mastectomy, an invasive technique in which the entire breast and the surrounding lymph nodes and chest muscles are removed. Subsequently, a technique called lumpectomy was developed – a relatively non-invasive technique. In this, only a discrete lump, usually benign tumor or breast cancer is removed, thus removing only a limited tissue as against the complete cancerous breast in the case of radical mastectomy. Around early 1990s, a new surgical technique, laparoscopic surgery, was developed that uses multiple telescopes to only remove the tumors. This new approach allowed the patients to recover fast and experience less pain, without sacrificing effectiveness. In the last decade, less invasive ways of destroying tumors without removing them are being studied and/or used. Cryosurgery (also called cryotherapy or cryoablation) uses liquid nitrogen spray or a very cold probe to freeze and kill abnormal cells as shown in fig 2. Lasers can be used to cut through tissue (instead of using a scalpel) or to vaporize (burn and destroy) cancers of the cervix, larynx (voice box), liver, rectum, skin, and other organs. Radiofrequency ablation transmits radio waves to a small antenna placed in the tumor to kill cancer cells by heating them [4].

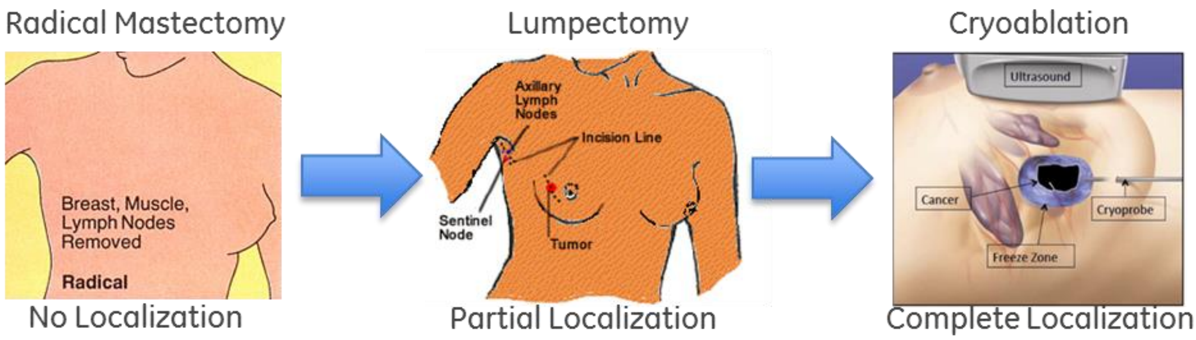

Fig. 2. Example of increasing localization – Cancer treatment

Aerospace components are either been developed for, or have come to prominence through, their use for aerospace purposes. These uses often require exceptional performance, strength or heat resistance, even at the cost of considerable expense in their production or machining. These are chosen for their long-term reliability in this safety-conscious field, particularly for their resistance to fatigue. Different types of materials ranging from metals, alloys, and composites are used based on the operating temperature, pressure, environment, fuel efficiency, performance and reliability [5]. Weight reduction is the essential driving factor for these components. Let us analyze the development of some of these components through the lens of trends of increasing localization.

Fan is the most critical part of a turbofan aircraft engine. 80% of thrust is produced using fan. Fan sucks in air which gets compressed in compressor, ignites in combustor and expanded in turbine section [6].

Step 1: Metallic monolithic fan blade in turbofan engines is used for sucking air into the engine as shown in Fig 3a. This fan is subjected to severe weather conditions and bird strikes during flight. Leading edge of the fan blade is the weakest part and gets immediately broken upon high velocity impact. If it breaks, it impairs the performance of the fan aerodynamically. In initial days there was no protection to the leading edge against these impacts - No localization.

Step 2: Later on we observe evolution of fan blades from metallic to composite. Composite blades are very brittle in nature compared to its metal counterparts and have very less impact strength. To withstand foreign object damage and bird strikes, only the leading edge of the composite blade is protected using a thin metallic strip as shown in Fig 3b - Partial localization.

Step 3: As said earlier, weight reduction is the key driving factor in aircraft industry, In the recent years, the development of hollow hybrid fan blades with composite airfoil pressure surface and suction surfaces for weight reduction, metallic leading edge for protection against bird strikes and cavities inside the blade filled with foam for improved impact strength are being explored- Complete localization depending on the region of the component.

Fig. 3. Example of increasing localization – Blades for gas turbines

4. Conclusions

A new sub-trend – Trends of increasing localization has been developed. To substantiate the sub-trend, case studies from two critical industries – aviation and healthcare, have been presented and discussed in a step-by-step method. In the process, the importance of trends of increasing localization – from no localization to partial localization to complete localization – due to technological advancement has been amply justified. The authors strongly believe that this new sub-trend will add more value to enhance the completeness of an engineering system.

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TRIZ AND VALUE ENGINEERING: DEEPER INTEGRATION AS INNOVATION ENHANCER

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Abstract

TRIZ and VA/VE (Value Analysis/Value Engineering) are well known and widely adopted value improving methodologies promoted by professional organizations and communities with education and certification programs. Both offer a complete cycle of problem identification/ problem solving/ solution implementation; VAVE is a structured problem solving tool with a deep focus on cost and value offered to the customer, while TRIZ core has proved its strength for the idea generation process. VA/VE foresees a creativity phase but proposes no structure for it, introducing it in its standard agenda as a classical free brainstorming. On the other hand, TRIZ core consists of a structured innovation philosophy, so they represent already a natural fit. VAVE is adopted with the goal to identify and remove cost, while TRIZ focuses on the technological aspects and the evolution of the engineering system, in an effort to drive development of more out of the box solutions. In this paper, the experience with a mixed approach for a NPI (New Product Introduction) project at GE is described, delineating and leveraging proven integration pathways. Commonalities and complements between VA/VE and TRIZ will be outlined, with two application examples of workshops at GE Oil & Gas Florence, with special regard on how function analysis is implemented in the two methods.

Keywords: TRIZ, VA/VE, Value Engineering, Function Analysis, Creativity.

1. Introduction: VA/VE, Function Modeling, TRIZ and Innovation

The Value Methodology was introduced in the 1940s at General Electric by Lawrence D. Miles [1], as an answer to a raw material supply scarcity; the approach was formalized into a method in 1946, and later was carried on by the SAVE society. Miles started analysing engineering systems in terms of functions that delivered value for customers. The process was refined into the so-called value analysis, with the goals of minimizing the total product life cost and eliminating unnecessary costs. Over the years it evolved as a systematic process to implement cost-out, based on a multidisciplinary team, with a formalized Job Plan as shown in Figure 1:

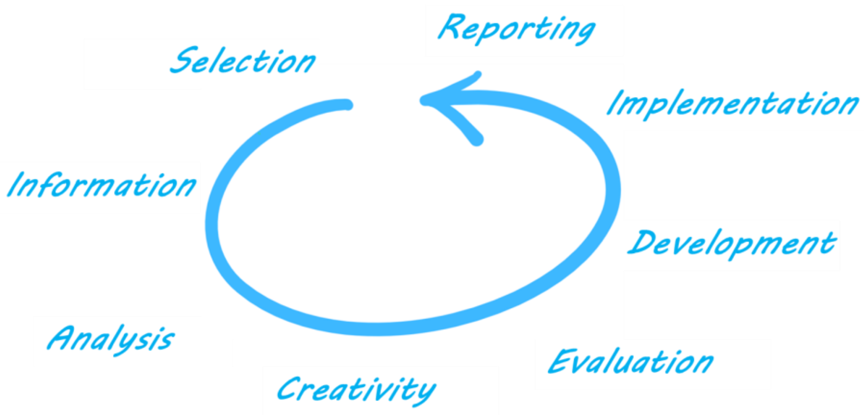

Fig.1. VA/VE Standard Job Plan as a Cycle

This methodology became mandatory for every US federal agency since the National Defence Authorization Act for the fiscal year 1996 [2], defined as "analysis of the functions of a program, project, system, product, item of equipment, building, facility, service, or supply of an executive agency, performed by qualified agency or contractor personnel, directed at improving performance, reliability, quality, safety, and life cycle costs.''

So it became an established paradigm for a process largely adopted by industry and US federal institutions as a means to leverage their activity and foster innovation, based on definition on the improvement of the value of a project by means of analysis of its functions. One of its more impactful effects was the introduction of Functional Analysis, which also emerged as TRIZ problem definition technique and is used for both engineering system and processes and business modelling [3]. The function model approach also fits very well with the new Design To Value philosophy introduced by McKinsey [4]. Nowadays, both VA/VE and TRIZ are widely used wherever a big effort on innovation is in place. They have been combined with other approaches and occasionally applied together. The combination of two or more value improving methodologies like lean, Six Sigma, DFMA, TRIZ and VAVE is often applied by current practitioners in order to get the maximum out of each toolset. A detailed description of literature contributions as well as direct hands-on experiences to understand how to better take advantage and optimize the joint use of both methodologies is captured in Paragraph 2.

2. Proven TRIZ and VA/VE combined pathways

The combination of TRIZ with several other product management and innovation methods has been already documented by many industry practitioners, business consultants and TRIZ Masters. Extensive activity on TRIZ-assisted Value Engineering Analysis has been reported among the Russian community in the 1980s and 1990s. Gerasimov and Litvin [5] showed how to reach VEA goals deploying all TRIZ tools, using Function Analysis to reformulate the key problem. Terninko et al. [6] explain how to use TRIZ in synergy with Quality Function deployment and Taguchi methods. Bukhman [7] recommends a Roadmap to optimize TRIZ effectiveness when used in conjunction with other methods for problem formulation and solving. Bolton [8] proposed to use TRIZ with Design for Manufacture and Assembly (DFMA) in order to maximize value and in [9] he claims TRIZ as one of the Value enhancing tools, using the functional approach to identify contradictions, with a cross- functional team as in VA/VE. Just like documented in Six Sigma [10], Bolton stated that when the target cost cannot be achieved, TRIZ can help to develop new solutions.

The described integration approach foresees a TRIZ expert who leads a team through the whole TRIZ inventive process and eventually identifies TRIZ as a powerful tool in conjunction with DFMA to be used at the early stages of product management. He also described how processes like Six Sigma, VA/VE and DFMA identify the actual problem to solve, but not how to solve it; in other words, they can be excellent problem identification tools but they need to be enhanced for the problem solving phase. Henschel and Czinki [11] introduce TRIZ mediated by Design Thinking to smooth the learning curve and raise acceptance.

More specifically, many works focus on TRIZ and VA/VE workshop integration. Gaikwad [12] points out the limitations of Osborne classical brainstorming and describes how he used TRIZ as a creativity tool of choice for VE workshop with a team of 14 people, aiming for quality improvement ideas, reporting 120 ideas generated, out of which 9 business cases were developed. No more information is given about the used TRIZ tools, TRIZ literacy among participants and time allocated for each session. Also Hanik and Kaufman [13] report bridging VAVE and TRIZ through the FAST model and confirm that the weakness of VAVE resides in the creativity phase. On the other hand it is described how TRIZ can bring the results out of the boundaries of capacity of the team members, though no other tools apart from the functional model and the inventive principles are used. Clarke [14] also leverages TRIZ for the idea generation process starting from the Innovation Situation questionnaire. Borza [15] describes the two methodologies to see how to take advantage of their complementary aspects rather than seeing them as competing approaches. He underlines their similarities in structure and the effectiveness of TRIZ for the creativity phase for VE, since it can enable people to hitchhike on ideas going beyond the limits of skills, knowledge and experience of the people in the session. He states that VAVE facilitators received training in structured innovation and gave good feedback, but no quantitative statistics are provided and no differences between the two functional analysis approaches are given. In [16] the integration of TRIZ and Value Engineering focused on the concepts of Ideal Final Result and Ideality. The FAST diagram of VAVE has the essence of The Function Analysis of TRIZ. VE is used to rank components regrouping the relative functions to which a value is attributed with a procedure borrowed by classic VE. The function value evaluation chart identifies the components to be improved cost-wise.

As a summary, all contributions confirm the power and flexibility of TRIZ, which as a methodology lends itself very effectively to be employed as a creativity enhancer in conjunction with several complementary methodologies and VA/VE in particular; in this case TRIZ application is confined to the creativity phase only and no precise roadmap on how to merge the different approaches is given, nor the detailed description on which TRIZ tools to employ. The report of the experience at GE will try to answer those questions.

3. TRIZ for VA/VE Online

In this section, the experience gathered during two projects is described; one project utilized a four-day workshop merging the two methodologies “online”, that is, using VA/VE and TRIZ during the same workshop; the other project combined them offline, having a TRIZ three-day session after four VA/VE workshops on just as many subsystems. This latter experience will be described more deeply in Paragraph 5.

The first workout was meant to apply Design To Value and VA/VE methodologies, enhanced by means of TRIZ tools, to an NTI (New Technology Introduction) Program for Oil & Gas. The team was composed of a multidisciplinary team of seven people, recruited from the engineering, service and sourcing departments, plus the VA/VE facilitator assisted by two TRIZ Practitioners, certified respectively Level 2 and 3. The VA/VE process is well known and structured and had previously already been applied in its standard form to a variety of project throughout GE Businesses and in particular for Oil & Gas at Florence Nuovo Pignone premises. The standardized VA/VE work plan includes a Creativity Phase, but not a systematic method to generate new ideas, so usually a classical free brainstorming is suggested and adopted at this stage. As explained in the paragraph before, TRIZ has been already described as a suitable tool to be inserted as a plug-in into this phase, but no examples of applications had been reported in GE Oil & Gas at the time, with only one case of application at GRC Bangalore, India. So the described workout was originally intended as a pilot for GE according to two novel aspects:

- Application of VA/VE to a NTI Program

- Plug-in of TRIZ tools to boost the Creativity Phase

The next paragraphs will offer a detailed description of this workout and synergy between the different tools. The workout was planned to follow the classic VA/VE structure, as shown in Figure 1, and was offered to two different teams, working on two separate projects. The teams gathered for a pre-workshop the week before the workout to define the project to be developed. One group followed the classic VA/VE agenda for a cost-out project with 20% cost cut goal, with a classical free brainstorming session, while the other followed the VA/VE integrated with TRIZ pathway, since the focus was on a NPI activity, with the goal to find novel solution and to meet a specific target cost threshold. The VA/VE session was common to the two groups until the creative phase when they were split and continued with a different schedule. Two TRIZ facilitators were engaged, and the selection of the TRIZ tools to be used in these sessions was left to their choice. As per their request, a brief TRIZ Introduction Session of about one hour was held for interested team at the end of day 1 in addition to the standard program, since only one person from this group had some TRIZ literacy. The goal was to have the team familiarized with the methodology and the TRIZ concepts and wording to be used during the subsequent phase. The time allocated for the TRIZ guided Creativity Phase was four total hours, split between Day 2 and Day 3. During the workshop though, more TRIZ concepts than originally planned were employed; a detailed description will be provided.

3.1. Problem Identification Stage: Function Analysis and S-Curve

At the beginning of the first day a general introduction of VA/VE was presented, focusing on the concepts of ideality, functionality and cost. The goal was to complete the project goal definition, random function identification and FAST diagram steps as per standard VA/VE Job Plan, so as to define the boundaries for the creativity phase. The Function Analysis in VA/VE framework is defined as active verb and measurable noun. The measurable noun makes it more general and increases the scope of coming out with new cost effective ways of doing the same function. But this does not exactly coincide with the Function Analysis according to the TRIZ approach, because functions are not identified between two components but from a single component. Functions are so listed object by object regardless of the target of the function. Moreover, in the VA/VE Function analysis the cost is included, while in TRIZ it can only be captured indirectly by means of the harmful functions. The main differences between the two approaches collected during the session are listed in Table 1:

Table 1. Function Analysis in VA/VE and TRIZ

VA/VE	**TRIZ**
Component analysis by cost	Component analysis for subsequent FA
System only	System and supersystem identified
Component: object (rest mass)	Component: substance (rest mass) or field
Function acts upon measurable noun	Function acts upon Component

Main Function: function for which the component is sold	Main Function: function for which the engineering system is designed
Ideality: ratio Functionality/Cost	Ideality: ratio of weighted sum for F,C
Functions: selected from a predefined list of of active verbs	Functions not predefined (suggested list)
FA for products and processes (different lists)	FA for products and processes (different function categorization)
Functions: required/ aesthetic/ unwanted	FA products: useful (basic,auxiliary,additional)/harmful, normal, insufficent,excessive
	FA processes: useful (productive,providing, corrective)/harmful, normal, insufficient,excessive
Excel template	Innovation Navigator™ or other software packages

The initial intention of the TRIZ facilitators was to leverage the FAST model to find harmful functions or useful function with insufficient performance, in order to identify contradictions; however, this was not as efficient because in VA/VE usually not many unwanted functions are found. The translation into the classical TRIZ function analysis is thus not straightforward, so it was chosen not to pursue this effort building a TRIZ function model to map the FAST diagram, but to identify during the FAST modeling phase the already recognizable contradictions, to be used as examples during the TRIZ introductory session.

During the first day other important observation were made: during the VA/VE introduction many options of improving value are available, so that the quality of intervention upon the system can be recalibrated in different ways, choosing whether to act more on the functionality or on the cost: VA/VE does not offer a systematic way to select one alternative in particular, whereas the S-Curve recommendations do. In fact the S-Curve theory can help at first to assess the phase where the project is and the recommendations can help decide what to follow. From this observation derived the decision to assess the system under analysis by means of the Innovation Navigator™ Express S-Curve tool: it resulted to be in the transitional stage, consistent with the existence of a prototype but not of marketable product. This assessment offered a more solid foundation to organize the creativity session.

3.2. Short TRIZ Introduction: project-focused examples

The TRIZ Introduction was organized as a short session according to previous experience gathered at GE Global Research Munich, described in [16], Paragraph 5, customizing a standard procedure used for similar short brainstorming introductions. The goal was to convey to the team short introductory notions about the methodology and its history and to propose upfront the definitions of the Inventive Principles, Engineering and Physical contradictions; in this way the team was able to take advantage of classical TRIZ tools in a pre-prepared form. The participants became familiar with the concepts on project related examples with immediate applications, in a learning-by-doing fashion. Also Su-Field models were used. The choice of the employed TRIZ tools reflected the experience gathered for short session described in [17] and the results of the S-Curve Analysis. The specific examples were prepared during Day 1 by the TRIZ facilitators while the team worked on the component list and the functional analysis according to the VA/VE approach; the whole team could then elaborate upon the presented contradictions. In this one-hour session some ideas were already emerging and were promptly documented for subsequent discussion. This phase reflected respectively already considered and discarded ideas or concepts already generated by the individuals (stage referred to as Idea Parking Lot in [17]).

3.3. Systematic Enhanced Creativity: different zoom levels

The Creativity Phase took place during Day 2 and Day3, with two hours each day. Table 2 depicts the TRIZ tools used for each day and the number of ideas resulting from the guided brainstorming. The first session during Day 2 started with a short Idea Parking Lot [17], not longer than 20 minutes, when the ideas start to diminish in number. Then, for a smoother start with TRIZ, Substance- Field models of solutions were proposed and the number of ideas started to increase again. This was done for several reasons: during the analysis phase, it emerged that the project could be considered in a pivoting phase. The Substance-Field modelling opened two ways: a zoomed out approach, going back to the basic physics: this allowed to having one class of model of problems defined as more radical, where no principle of action was assumed (stepping back to S-Curve Stage 1) and an harmful interaction was identified, and one where the initial principle of action was maintained, solving an insufficient interaction. It was evident how Substance-Field analysis enabled people to distinguish between concepts that could remove the harmful effects and ideas that in turn could remove the cause, solving the problem from different points of view, identifying at the same time opportunities to push the technology limits. This also emerged after a Multiscreen Analysis based on reflection of the system. In addition to that, the visual nature of the presented Su-Field models helped the team get started with the creativity phase in a more natural way. On Day 3 the team zoomed back in to the existing system, focusing on the results of the FAST diagram where five functions were identified as responsible for the bigger cost contribution. Engineering and Physical Contradictions were then written around the parameters affected by those functions, resulting in the more impactful contributions in terms of number of ideas. Some further insights were given mapping the Trend of Increasing Dynamization to the existing system.

Table 2. TRIZ Tools and Results. In *italic* non-TRIZ tools

Day	Time [hrs]	Tools	Ideas
1	1	*Idea Parking Lot* [17]	13
2	2	Substance-Field Models 1.1.3,1.1.4, 1.2.1	13
		Substance-Field Models -F 1.2.4	10
		Multiscreen	
3	2	Engineering Contradictions	5
		Physical Contradictions- Separation in Time	5
		Physical Contradictions - Separation in Space	5
		Physical Contradictions - Separation at System Level	3
		Physical Contradictions - Other	23

3.4. Down selection, Function Oriented Search, Feature Transfer

The Job Plan for day 4 was the Evaluation Phase, that is, the idea down selection process. According to the VA/VE pathway, the different concepts need to be regrouped according to certain labels. The team agreed on five different labelling tags and decided to scale them according to the Technology Readiness Levels (TRLs) defined for the Oil & Gas Industry by the Norm API 17N. For each of the five tag groups, one or two ideas were selected, for a total of seven concepts, all below TRL3. During this phase other TRIZ tools were employed to help formulate solid decisions about different concepts: the most useful ones were the feature transfer and the function oriented search tools, implemented by means of a semantic search engine on a patent database. This helped identify physical effects used to solve analogous problems.

4. Workout Outcomes

The workout with a merged VAVE and TRIZ approach was quite successful in terms of number of identified possible solutions, which at the end were around 70 in total, accounting for repetitions that occurred during the different sessions (see Table 2). The participants acknowledged that TRIZ boosted the VA/VE creativity phase, noticing that also non-technologists were able to strongly contribute to the formulation of technical ideas. With respect to already documented experiences, new TRIZ tools were employed and an optimized approach for short TRIZ sessions was adopted. The most appreciated new introductions were the S-Curve Analysis at the very beginning, that offered a strong tool to support the decision on how to shape the following TRIZ sessions, and the adoption of the TRL scale and the function oriented-semantic search for the idea evaluation phase. The parallel team who applied classical VA/VE with free brainstorming worked on a different technology, so a direct comparison can be misleading; anyway it can be noticed that the team could formulate a similar quantity of ideas, but they were perceived as much less disruptive, leading to the proposal of small and incremental modification of the existing systems, with no big innovative content. The original Workshop Plan foresaw the adoption of TRIZ concentrated to the creativity phase. This experience showed that distributing TRIZ tools along the Information, Analysis, Creativity and Evaluation (see Fig. 2) phases can strengthen a lot the VA/VE process both from for the number of generated ideas and from the level of system insight and zoom level at which the ideation process should take place.

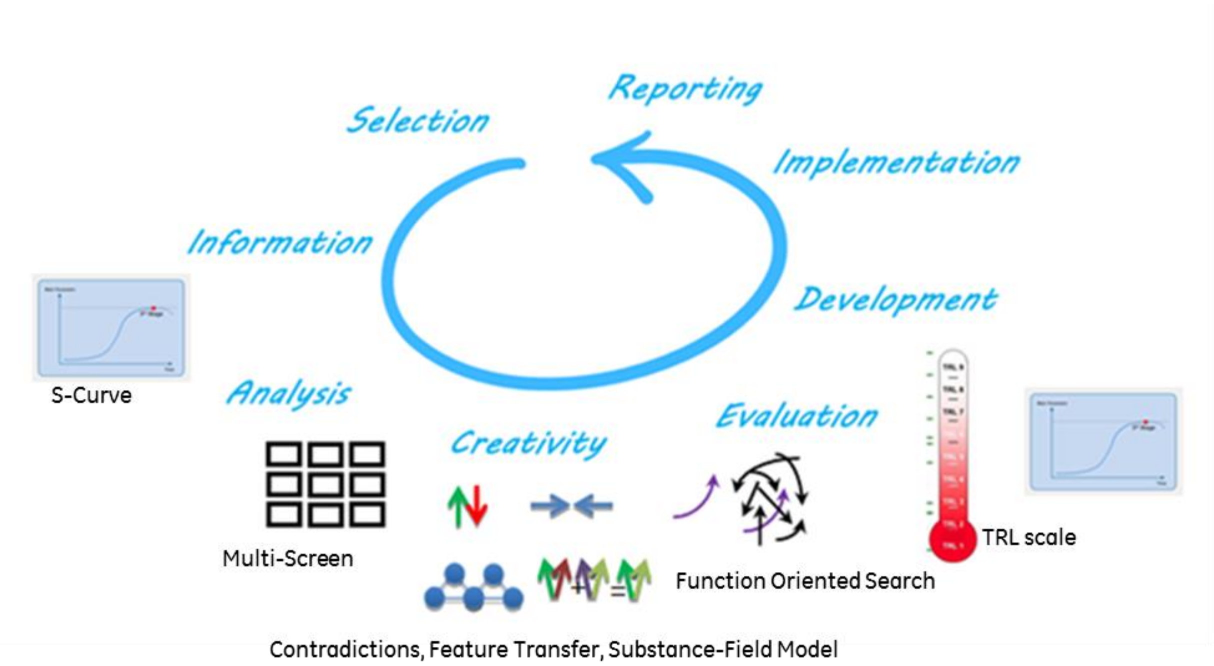

Fig.2. VA/VE + TRIZ Workout

Other takeaways include how to modulate the content of the workshop between VA/VE and TRIZ tools: the effectiveness of their combination is enhanced if the project phase is taken into account. Since the chosen level of focus can either offer the opportunity to pivot and drastically change the concept, or to zoom into the system to identify cost-out opportunities changing as little as possible, it is advisable to enhance the stress on TRIZ and Creativity at the early stages of the projects. A new session with more of a zoom-in approach can be added at the later stage with a bigger attention to the detailed emerging contradictions where the biggest costs are found. This is useful when the NPI is more advanced and the focus is on system optimization. This was experimented and confirmed by a three-day TRIZ session on a different project, described in Paragraph 5.

The participants appreciated TRIZ as a powerful tool: their perception on the pilot workshop was captured by a survey, results of which are reported in Table 3:

Table 3. Answers to a Participants Survey

Question	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
I understood how to effectively apply VAVE + TRIZ to my processes	67%	33%			
TRIZ adds value to VAVE	67%	33%			
The Day 1 introduction was enough to be able to have a working understanding on how to use the tools	33%	67%			
TRIZ enabled the team to developed more ideas.	67%	33%			

Some ideas were unlikely thought of without TRIZ	33%	33%	33%		

5. TRIZ for VA/VE offline

TRIZ was later applied during a dedicated workshop for a new NPI project. The goal was to formulate innovative concepts, leveraging on the functional analysis and cost structure previously identified during four classical VA/VE workouts on separate subsystems. The TRIZ facilitators met the team during a one-day pre-work session aimed to define the workout structure, elaborating at first on the S-Curve and Multiscreen analysis. VA/VE results were very helpful to the phases of problem definition and component analysis, guiding also a preliminary Cause Effect Chain Analysis. In this way the subsequent 3-day workshop was organized alternating common introductory sessions at the beginning of each half day, followed by workouts during which the team was split into 3 different groups, two of which working on incremental concepts and one chasing more disruptive ideas. The introductory session were design to last less than one hour to allow the teams to get familiar with the proposed TRIZ tools on project-related examples and proceed with the creative phase. This allowed a more dynamic modulation of the creativity sessions, stressing the incremental and disruptive innovation efforts introducing the most suitable tools at the right time, with more than 100 generated ideas. Throughout the workshop the focus was on TRIZ tools, thus VA/VE idea down-selecting approach was very useful for concept post-processing, enriched with S-Curve and TRL concepts for idea regrouping and labelling.

6. Conclusions: more than Creativity Brainstorming

The experience gathered during the described workshops at GE Oil & Gas in Florence showed that the TRIZ methodology can enhance VA/VE and Design To Value activities far beyond the standard four hours scheduled for the VA/VE Creativity Phase. Moreover, it offered further insights on how to merge the two approaches more smoothly beyond the VA/VE Creativity Phase, suggesting the choice of the proper TRIZ tools according to the desired Technology Readiness Levels for the solutions and the integration of further TRIZ concepts. In particular S-Curve Analysis and Function Oriented Search can fit very well with other VA/VE stages, such as FAST and Idea down-selection. Conversely, VA/VE concepts can strengthen the TRIZ Innovation Process, since TRIZ is very strong for idea generation, but lacks a structured approach to help a robust concept selection. Detailed description of the structure of the different workout days are given respectively in Table 4 for the *TRIZ for VA/VE Online* session and Table 5 for the *TRIZ for VA/VE Offline* workshop:

Table 4

TRIZ for VA/VE Online

Workshop Day	Activities
Day 1 AM	Introduction: VM Overview – The Power of VA/VE – Value concept Information: Project Selection – Goals - Scope – **S-Curve, MultiScreen** Random Function Identification
Day 1 PM	Function Analysis: FAST Diagram **TRIZ Intro: Brief History, Contradictions, Su-Field Examples**
Day 2 AM	FAST Diagram, Cost/Function Lecture and Matrix, **Choice of F/C**

Day 2 PM	**Creativity: TRIZ Engineering and Physical Contradictions**
Day 3 AM	**Creativity: Su-Field Models, MultiScreen**
Day 3 PM	Evaluation: Categorize – Rank – Combine T-Chart , **S-Curve**, **TRL**, Idea Selection Matrix, **Function Oriented Search**
Day 4 AM	Development: Concept Proposal Worksheet
Day 4 PM	Preparation and Team Presentation

Table 5

TRIZ for VA/VE Offline

Workshop Day	Activities
Prework AM	Introduction Idea Parking Lot, TRIZ Problem Definition, S-Curve Analysis,
Prework PM	Component List from 4 different VA/VEs on subsystems CECA Introduction, first Engineering Contradictions identification
Day 1 AM	TRIZ Intro, IFR, Root Cause Analysis, Multiscreen
Day 1 PM	Split into 3 Groups, Engineering and Physical Contradictions
Day 2 AM	Engineering and Physical Contradictions, Trends
Day 2 PM	Trimming
Day 3 AM	Idea Down-selection
Day 3 PM	Idea Down-selection, Team presentation

So we can outline the learnt lessons in the following list:

- TRIZ has already been successfully applied as VA/VE and other methodologies creativity enhancer, as shown by many literature papers and conference contributions; its use in the VA/VE process has been so far restricted to the creativity phase only, and there are few reports on which specific tools have been adopted: Contradictions, Ideal Final Results and Innovation Situation Questionnaire
- Adding a S-Curve Analysis as early as possible to the VA/VE process can represent a powerful tool to assess the technology status and the resulting recommendations could help significantly shape the creativity phase when deciding whether the desired level of innovation should be incremental or disruptive
- Ideally the S-Curve Analysis, along with a preliminary Cause/Effect Chain Analysis to identify key problems, should be done so that additional technologists may be included in the following workshop, and the TRIZ facilitator(s) should be involved
- Substance-field Models (TRIZ for VA/VE online) and Trends (TRIZ for VA/VE online) proved to be very powerful tools for generating disruptive concepts, while Engineering

and Physical Contradictions were very effective for more conservative approaches where the Engineering System needed not to be changed radically

- Adding TRIZ tools such as feature transfer and function oriented search to the Evaluation phase can offer solid decision support; also the system assessment, both in terms of S-Curve and/or TRL can be of great help in categorizing the ideas
- VA/VE offer a quite strong method for the idea evaluation phase, while TRIZ lacks a structured approach to the post-processing phase and can profit from VA/VE approach
- It is advisable to enhance VA/VE workshops for low TRL and NPI projects, whenever a strong innovative pivot is needed; higher TRL systems can better profit from classic VA/VE cost structure identification process
- GE saw value in recommending to merge the two approaches further and launched new pilots to assess the effectiveness at different TRL levels, in order to increase product and project sustainability
- GE experience underlined the value offered by repeating similar workshops for the same project at different TRL levels, modulating the TRIZ/VA/VE content, so as to shift smoothly the focus between radical innovation and cost-out intervention

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TRIZ BASED INSIGHT PROBLEM SOLVING AND BRAINWAVE ANALYSIS USING EEG DURING AHA! MOMENT

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Abstract

Psychological inertia is mental barriers that hinder one's creativity and problem-solving ability which often go unrecognized. With more expertise in ones' specialized field, people tend to be more captured within their psychological inertia. On the other hand, the concept of resources in TRIZ is known to be powerful for enhancing creativity and solving inventive problems and is integrated into many advanced TRIZ tools and knowledge base, such as ARIZ and 76 Standard Solutions.

Besides, in cognitive neuroscience, the psychological process of creative thinking has been actively studied using the electroencephalograph (EEG). One of the most interesting finding is the research study which suggests that at the moment when insight problem is solved with Aha! experience, the gamma wave is ignited and neuronal synchronization is observed throughout the brain.

This paper aims to demonstrate how psychological inertia usually occurs with people with more expertise in ones' specialized field, and how they can overcome psychological inertia by using the concept of resources in TRIZ. The problem of 2 equivalent circuits in 2 black boxes is tested with 42 students of electrical engineering program and the result shows that students with no prior knowledge of the concept of resources in TRIZ try in vain to solve the problem within their expertise of circuit analysis, while most of the students with the knowledge of the concept of resources in TRIZ can solve the problem easily within a short time. Besides, 2 teachers from electrical engineering program have participated in the testing with EEG recording while solving the problem and the result shows that participant with the knowledge of the concept of resources in TRIZ can successfully solve the problem and EEG recording confirms the synchronization of gamma wave during Aha! moment when the participant comes up with an insight solution.

Keywords: TRIZ, Insight problem, Psychological inertia, Creative thinking, EEG, Aha! experience.

1. Introduction

Creativity is an important aspect of human life. Creative thinking, ranging from the problem of solving simple puzzles to the problem of attaining innovative ideas, renders progress to human history. Process of creative thinking is composed of a psychological process involved in bringing new ideas and innovation. Studies of the psychological process in thinking process using a brainwave analysis have been the objectives of cognitive psychology and neuropsychology for a long time [1], but paper with clear explanation into the mechanism of creativity is not much found.

One of the important approach to the mechanism of creativity is the concept of insight which was firstly introduced by Kohler, a Gestalt psychologist in 1969 [2]. According to the approach, the problems that human beings are trying to solve can be divided into two types called insight problems and non-insight problems. Insight problems are uniquely solved by insight while non-insight problems are usually solved by analytical method with known steps or procedures. Insight problem solving is characterized by problem solver with no past experience trying in vain to solve the problem and finally reaching the mental block or impasse where he/she cannot continue with the problem solving, then by the restructuring of the problem or looking at the problem from new angle, suddenly, the solution emerges with insight. This moment of insight has been referred to as the Aha! moment or Aha! experience.

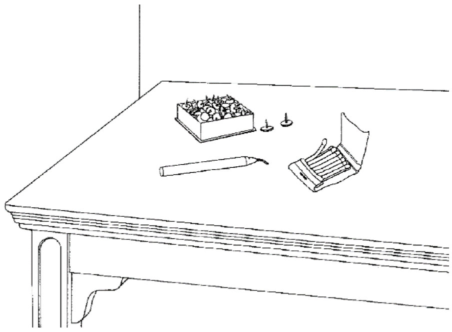

Fig. 1. The Candle Problem

The well-known example of insight problem is the candle problem designed by Duncker in 1945 [3]. Given a candle, matches and a box of thumbtacks on the table, the participants are requested to fix and light a candle on the wall in a way that the candle wax won't drip onto the table below. Many of the participants are locked in what Duncker calls “Functional Fixedness” in which most people look at an object only in the way it is traditionally used. Most participants think the box is just a mere container of thumbtacks and they are mentally blocked. The moment when they restructure the problem and find out that the box can be used as a candle stand, all of a sudden, the answer comes up to their minds.

The author is interested in finding a systematic way or tool that can be used to explain and reveal the clue for restructuring the problems so that solution can be reached with insight. The author has involved in researches and applications of theory of inventive problem solving (TRIZ) [4] and has learned TRIZ’s insight problem which is called the problem of corrosion test [5, 6] which is explained in Fig.2 as follows,

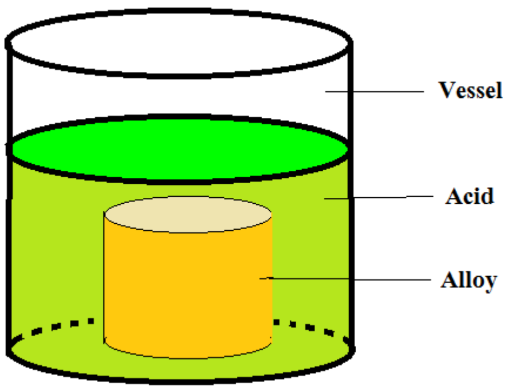

Fig. 2. The problem of corrosion test

Alloys with various composition are tested to measure their acid resistance. After measuring the mass of the alloy, it is immersed in a vessel containing strong acid liquid. And after a predetermined length of time, it is taken out to measure the mass again to calculate the acid resistance from the loss of the mass of the alloy. The test vessel is made of a strong acid resistance platinum which is expensive. As a result, test has to be executed sequentially which makes it a time consuming process. How can the efficiency of the experiment be improved with minimum cost ?

In the early 1970s, Altshuller, the founder of TRIZ, showed that this problem can be solved using the concept of resources in TRIZ. With the available resources inside the system and its environment, the ideal system can be obtained without the necessity to introduce expensive resources from outside. In this problem, the alloy itself can be used as resource to be prefabricated as container by digging a hole into it in advance so that it can hold strong acid liquid. By doing so, parallel test can be carried out which improves efficiency of the experiment. In this way, by using the concept of resources, restructuring the problem can be done effectively and the idea comes up all of a sudden with aha! experience. This makes it an insight problem. In addition, when using the concept of resources, not just only the visible ones, all hidden resources inside the system and its environment can also be considered to check whether they can be used to solve the problem.

This paper aims to confirm the above mentioned TRIZ’s concept of resources being used as a tool to restructure the problem so that it can be solved with insight. The test problem is set to be distinguishing 2 equivalent electric circuits inside the 2 identical black boxes. The problem which requires the knowledge of electrical engineering is tested with 42 students from the electrical engineering program of the Thai-Nichi Institute of Technology. By mobilizing all available resources that are visible and hidden inside the system and its environment, the problem can be restructured by changing the point of view to be out of the box.

In addition, in cognitive neuroscience, the psychological process of creative thinking has been actively studied using the electroencephalograph (EEG). Relationship between brainwave and the mental state is being elucidated [1]. In particular, it is found that alpha wave is highly involved with mind state of relaxation while the beta wave is well known to occur in the mind state of attentiveness. Besides, one of the most interesting finding is the research study which suggests that at the moment when insight problem is solved with Aha! experience, the gamma wave is ignited and neuronal synchronization is observed throughout the brain [7].

Therefore, the problem of distinguishing 2 equivalent electric circuits inside the 2 identical black boxes is also tested with 2 teachers from the electrical engineering program. Relaxation state, attentiveness state and the state of Aha! moment during the experiment are monitored and recorded by using EEG to analyse the data and compare the result with previous finding.

2. Method

The author has deployed the black boxes problem of 2 electric circuits [8] as shown in Fig. 3 which was previously used in other research by author [9]. Each of the 2 equivalent electric circuits is placed inside the 2 identical black boxes with only the terminal X-Y visible from the outside the box. As the 2 electric circuits are actually equivalent circuit, no matter what measurement or circuit analysis is used to test the terminal X-Y, the result is always the same for both circuits. So it is impossible to distinguish which black box contains which circuit by measurement or circuit analysis. But if the concept of resources is deployed, the hidden resources of fields will be easily recognized. Even without connecting anything to the terminal X-Y, circuit with current source is in a closed circuit, while circuit with voltage source is open circuit. The closed circuit will have current flow which generate magnetic field and thermal field which can be easily detected outside the box.

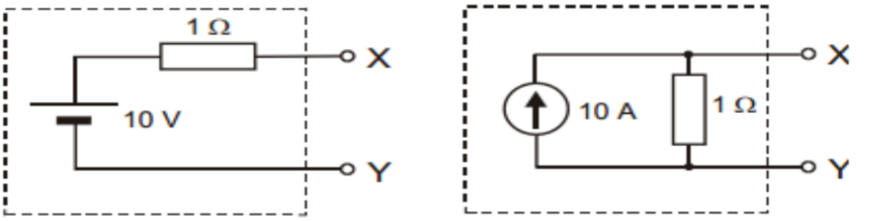

Fig. 3. The problem of 2 equivalent electric circuit black boxes

The problem of 2 electric circuit black boxes is tested with 42 students of the electrical engineering program. The problem is explained and the students are told to use any methods and any tools, so long as not to break the box, to distinguish which black box contain which circuit and write the answer on the test paper within five minutes. For students who fail to answer, the concept of resources is explained for the period of 5 minutes with example not directly relevant to the electric circuit problem to give them some hints, and immediately, one more time, the same electric circuit black boxes problem is asked again and the students have to write their answer on the test paper within 5 minutes.

In addition, 2 teachers of the electrical engineering program participate in this test as volunteers with EEG to monitor their brainwave during the experiment. The 2 teachers gave written informed consent to participate in the research. Fig.4. shows the experimental environment when the participant tries to solve the problem while being monitored and recorded the brainwave.

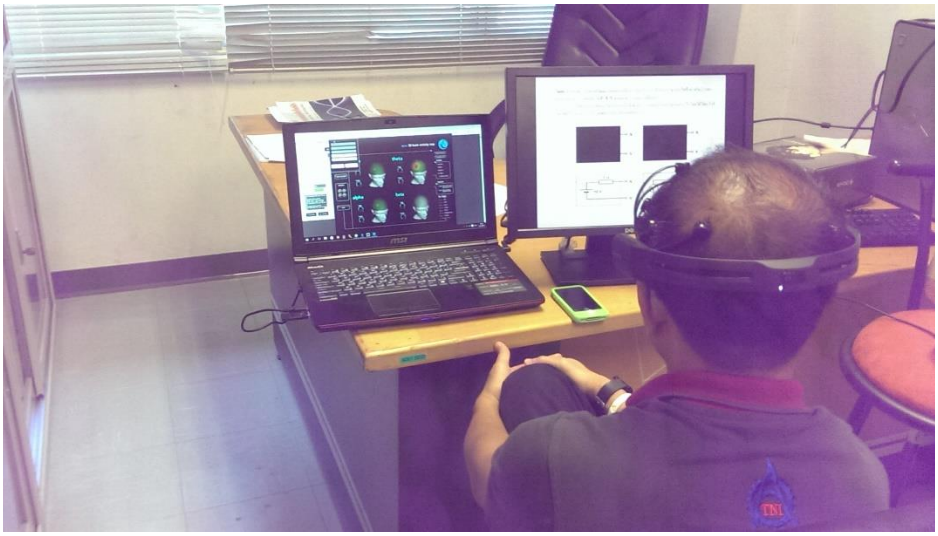

Fig. 4. Experimental environment of the brainwave measurement

The procedure of experiment is shown in Table.1. The participant is explained about the procedure and get ready for the experiment by wearing the EEG headset. At step 1, the participant looks at the white screen of the computer in the state of relaxation without movement or eye blink while EEG is recorded for 2 minutes. Step 2, the problem is shown on the screen of computer and the participant tries to solve the problem while EEG is recorded for 2 minutes. The participant is instructed to raise his hand as soon as he comes up with the insight solution. At step 3, if the answer is wrong or the test fails, the participant is explained about the concept of resources in TRIZ for 5 minutes with example not directly relevant to electric circuit problem to get hints while the EEG recording is turned off. At step 4, the problem is shown on the screen of computer and the participant tries to solve the problem again while EEG is recorded for 2 minutes.

Table 1

Procedure of experiment

Step	1	2	3	4
Task	Rest	Test	Learn	Test again
Time	2 min	2 min	5 min	2 min
EEG	On	On	Off	On

3. Results and Discussion

Table 2 shows the result of the test conducted on 42 students of the electrical engineering program (average age is 20, 32 males and 10 females). At the first test, most of the students cannot answer the question, there is only 1 student who can give the correct answer. The success rate is as low as 2.4 %. The student with correct answer is excluded and the rest of the 41 students are explained about the concept of resources in TRIZ for 5 minutes with example not directly relevant to electric circuit problem to get hints after which they are told to solve the 2 electric circuit black boxes problem again. This time, there are 17 students out of 41 students who can come up with the correct answer and the success rate goes up to 41.5 %.

Table 2. Test result of the 2 electric circuit black boxes problem

Task	Test 1 (No prior knowledge of TRIZ's concept of resources)	Test 2 (With knowledge of TRIZ's concept of resources)
Number of students	42	41
Time (minute)	5	5
Correct solutions	1	17
Success Rate (%)	2.4	41.5

It is a remarkable result and the question is why in the first test, almost all the students fail to come up with the correct answer. This can be explained with the concept of "Functional Fixedness" proposed by Duncker in 1945, but the concept of "Psychological Inertia" stressed by Altshuller in the year 1946 is more widely used to explain the phenomenon. It is stated that the problem solvers are usually obsessed with "psychological inertia" when trying to solve problem. If they cannot overcome their psychological inertia, they can hardly look at the problem with new angle and cannot come up with the correct answer. Especially, as their expertise is higher, the wall of their psychological inertia will also be higher. The students from electrical engineering program have already passed the subject of circuit theory so they are strong at circuit analysis. When they see the terminal X-Y of the black boxes, they are obsessed to find something to connect to the terminal and measure the current or voltage from the terminal, trying to distinguish the electric circuit in the black boxes without success. The result will be the same for both circuit because they are equivalent circuit. If they don't restructure the problem and think outside the box, they will not be able to come up with the correct answer.

Next the result of EEG experiment with 2 teachers from electrical engineering program are shown in Fig. 5 and Fig.6 respectively. Emotiv Epoc+ wireless EEG system is used in this experiment due to its low cost and suitability for research work. The raw data from Emotiv EEG system is exported to EEGLAB which is the open source software environment for analysing the brainwave. After removing artifacts and DC base line in the pre-processing step, power spectrum of different frequency during the relaxation state (Resting) and attentiveness state (Testing) of the experiments are calculated and shown in Fig.5. As shown in Fig.5, with no insight, the alpha wave appears at the frontal cortex during the relaxation state and decreases during attentiveness state while beta wave slightly increases during attentiveness for both participants. This is in accordance with the previous finding which says that alpha wave is highly involved with mind state of relaxation while the beta wave is well known to occur in the mind state of attentiveness [1]. In addition, both Subject A and Subject B seems to have higher Theta wave during relaxation than during attentiveness state. This may be caused by their drowsiness during the resting period. And for both subjects the gamma wave appear slightly during the attentiveness state.

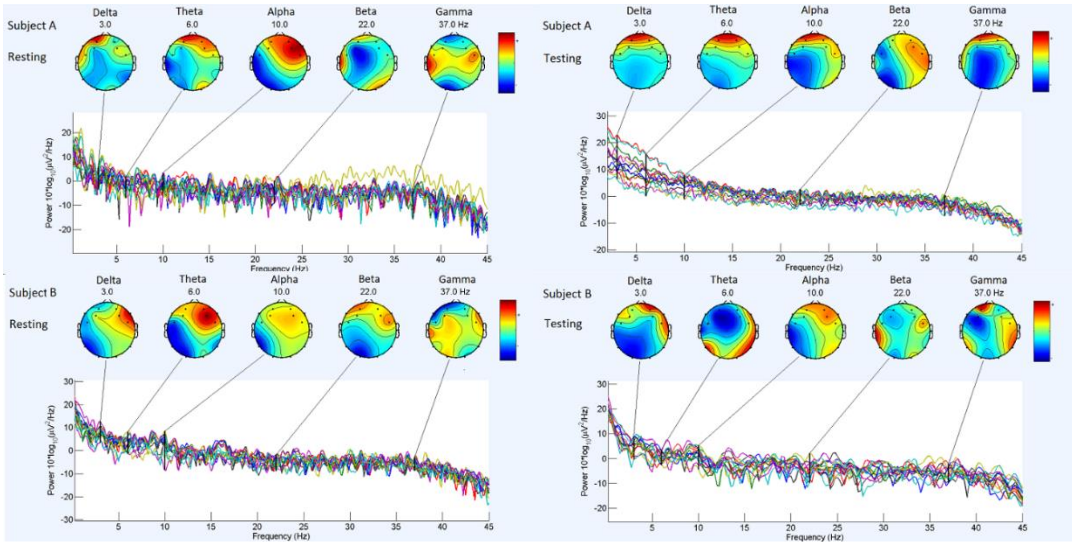

Fig. 5. Power spectrum of different frequency during the relaxation state and attentiveness state of subject A and subject B with no insight

Fig. 6 The 3D brain mapping of power spectrum of various brainwave during Aha! moment

Next, after learning about the concept of resources in TRIZ, both participants challenge to solve the same problem again with Subject A fails to give the correct answer and Subject B succeeds and comes up with the insight solution. The 3D brain mapping of power spectrum of various brainwave during certain point of time is shown as in Fig.6. There is no significant gamma wave during the Testing period in Subject A who fails to come up with the correct answer. The gamma wave seems to appear at the moment of insight in subject B at the end of the Testing period as shown in Fig. 6. Subject A does not show any noticeable gamma wave throughout the experiment while Subject B shows a remarkable gamma wave during the moment he comes up with the solution near the end of the experiment which supports the discovery of the gamma wave synchronization during Aha! experience by Rodriguez [7].

4. Conclusions

In this paper, it is confirmed with the 2 electric circuit black boxes problem that psychological inertia blocks problem solver from insight to the solution, and in order to overcome psychological inertia, TRIZ's concept of resources plays an important role in restructuring the problem, giving the problem solver a new angle to look at the problem where insight solution can come up instantly. Besides, it can be said to some extend that during the moment of Aha! experience, the gamma wave is ignited and neuronal synchronization is observed throughout the brain. For further research, more quantitative research with more subjects and more tasks will be needed to confirm the above finding.

Acknowledgements

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TRIZ FOR THE DEVELOPMENT OF NEW MATERIALS: SOME PRELIMINARY IDEAS

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Abstract

To our knowledge, at the moment, despite some publications about TRIZ related to the field of materials science, TRIZ turns out to be poorly instrumental and very rarely applied for the development of new materials, which is the core field of materials science. The reasons for that situation are analyzed. It is recognized that a new material is an invention if at least one contradiction between its properties is resolved, and within the frame of Ashby diagrams, a quantitative approach allows to derive an objective criterion for such an invention, as well as a degree of invention, complementary to the qualitative level of invention by Altshuller. This quantitative approach can be applied to engineering systems as well. On the basis of the example of the famous dilemma between strength and ductility of metallic materials, it is shown that the structural strategies used by metallurgists to overcome the underlying contradiction match well with some known ways of resolving physical contradictions according to TRIZ. These findings fund the basis for a rough program the aim of which is the adaptation and development of TRIZ for the design of new materials.

Keywords: material, optimization, contradiction, degree of invention, criterion for invention.

1. Materials and materials science

A material is a usually a solid substance the intent of which is to be used in certain applications. Materials science (and engineering), is a vast interdisciplinary field which theoretically and experimentally studies the relationships between processing, structure and properties of materials, so as to mainly optimize material properties, discover and develop new materials. Materials range from crystalline to non-crystalline, and usual examples of materials are: ceramics and glasses, polymers, semiconductors, metals and different composite materials. More recent material categories are for instance nanomaterials and biomaterials [1].

2. Links between materials science, innovation and TRIZ

2.1. Development of new materials as a driver for technological innovation

Within the technosphere, a large amount of technologies rely on the use of specific materials, via system components which are often made of materials (in the modern TRIZ meaning: some components may be powdered, liquid, gaseous, a plasma, or even a field). The performance of a significant fraction of these technologies is limited by the performance of the commercially available materials. Therefore the development of new materials is an important factor of the technological evolution. As TRIZ is a systematic innovation method, it sounds logical that TRIZ could play a significant role in the development of new materials.
Actually the present article is an attempt in this direction.

2.2. Materials in current TRIZ tools

Materials appear in some TRIZ tools:

- Among the 40 inventive principles, two of them, namely “Porous Materials” and “Composite materials”, relate explicitly to this topic, and can be illustrated with interesting examples [2]. Besides, “Thermal expansion” is another, less explicit one.
- In the scheme of evolution of engineering systems proposed by Y. Salamatov, from a mono-system to more complex systems, after the expansion of a system (i.e. more complexity) follows its convolution (i.e. less complexity). Ultimately the convolution phase ends when the system becomes a mono-substance [13], which fulfils the necessary functions. This mono- substance may be a (solid) material, possibly a so-called smart material.
- In the database of scientific effects, numerous effects rely on the use of specific materials, so as to solve a problem out of the field of materials science, or in materials science (e.g. for material characterization) but not for the design of new materials.
- Some Su-Fields suggest the transition towards specific materials (ferromagnetic materials, capillary-porous material), just like the Trends of Engineering Systems Evolution.

In practice, all this seems poorly instrumental for the materials scientist devoted to the development of new materials, because of its too general character. That is a trivial reason why the materials scientist usually looks at TRIZ as only interesting for the systematic innovation in materials processing, where its application is more obvious.

2.3. TRIZ for materials science

However, an Internet research of the bibliography in English language related to materials science and TRIZ has been carried out and delivers the following types of articles:

- Study of the link between TRIZ trends of evolution and other already identified trends in another method (e.g. eco-innovation, in ceramics industry products) [3];
- TRIZ applied for the design of new products based on current materials (e.g. new design of a metallic part for the building industry) [4][5];
- TRIZ as a means to interpret (with S-curves and the concept of ideal substance) discoveries in a specific field of materials science (e.g. superconductivity in chalcogenide glasses), besides promises of future inventions (e.g. based on high-temperature liquid semi-conductors) [6];
- TRIZ applied for the improvement of a material manufacturing process operation (e.g. plasma treatment of polymers) [7];
- TRIZ applied for the search of new applications of a novel process providing original material properties besides new design possibilities (e.g. sheet metal profiles manufactured by linear flow splitting) [8];
- TRIZ applied in companies which produce raw / semi-product materials, without more details about its application (e.g. Gold Molybdenum technical group in China) [9];
- TRIZ as a means to solve physical contradictions at the level of systems with the help of smart materials [10].
- TRIZ as a means to interpret strategies for the prevention of thermal deformations [11].

As a conclusion, despite some applications of TRIZ in the field of materials science, its application for the development of new materials seems publicly non-existent, at least from the bibliography in English language. It turns out that the only findings on the topic emanate from authors, including A. Kynin and V. Mikhailov, who have published their works in Russian [12].

2.4. Causes for the difficult application of TRIZ for the development of new materials

TRIZ teaches us to clearly define the problem to solve. In the present case the problem to solve is: how to develop a new material with the required combination of properties with the help of TRIZ tools? [12].

It is believed there are two main reasons for the difficulty of this problem:

- As introduced in § 2.2, TRIZ is too general and not adapted to materials science. Indeed TRIZ has been developed for systems made of components which fulfill clearly defined functions, whereas materials are hierarchically inferior to systems and components, and possess properties, rather than fulfilling functions. Beside functions, components of a material are uneasy to define, all structural features being strongly interrelated at different length scales (from nano- to macro-). Also the concept of invention is not straightforward.
- Another reason is intrinsic to materials science itself: the structure and the properties of a material depend on many different complex phenomena occurring at different length scales, and which are not completely scientifically understood. Consequently, contrary to a lot of engineering disciplines (e.g. mechanical, electrical, computer, civil), there are practically either no quantitative models which forecast sufficiently accurately the real structure and real properties of materials, or these models exist but they don’t predict all the required properties. So if a materials scientist wishes to validate his recent new ideas about the design of new materials, tedious experimental work is very often necessary.

3. Towards the adaptation of TRIZ for the development of new materials

3.1. Optimistic position and rough plan for the future

The original and initial statement of TRIZ itself, similar to that expressed by David Pye, professor of design at the Royal College of Arts (England) is that “most design problems are essentially similar no matter the subject of design is” [13]. If applied to the specific field of the development of new materials, this statement invites to think that TRIZ has a real potential to help developing new materials.

It is believed one should first do the following:

- Adapt the TRIZ concepts (e.g. invention, components, functions) to this specific field;
- Adapt and expand some TRIZ tools for this specific field. It is believed this work should begin with the TRIZ tools which are completely universal, like the physical contradictions and the ways to resolve them (by bypass, satisfaction or separation of the contradictory requirements).

3.2. The concept of contradiction in the development of new materials

TRIZ teaches us that an invention is the result of the overcoming of at least one contradiction. Actually contradictions do occur during the development of new materials. Materials scientists are much aware of “compromises”, “dilemmas”, caused by “mutually exclusive” properties. So contradictions occur between material properties. And it is often possible to formulate physical contradictions.

For the sake of the illustration of this statement, let us take an example which is basic knowledge for metallurgists: if an alloy gets stronger, its ductility decreases. Here both properties are measured after a complete tensile test, and extracted from its associated stress-strain curve (see Fig. 1: strength is the maximal tensile stress of the curve, while ductility may be quantified by the maximum strain at the end of the curve ε_{max}).

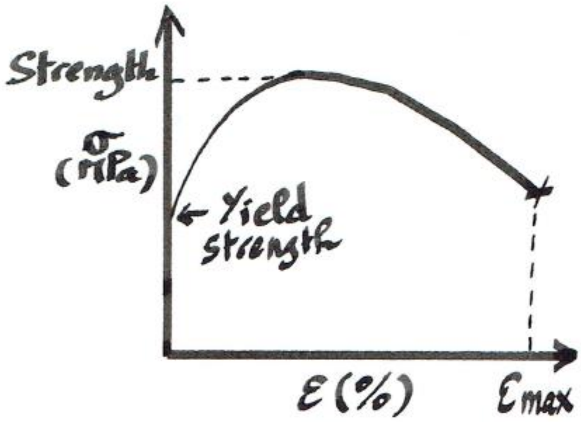

Figure 1: Typical stress-strain curve of a metallic alloy in a tensile test (after [14])

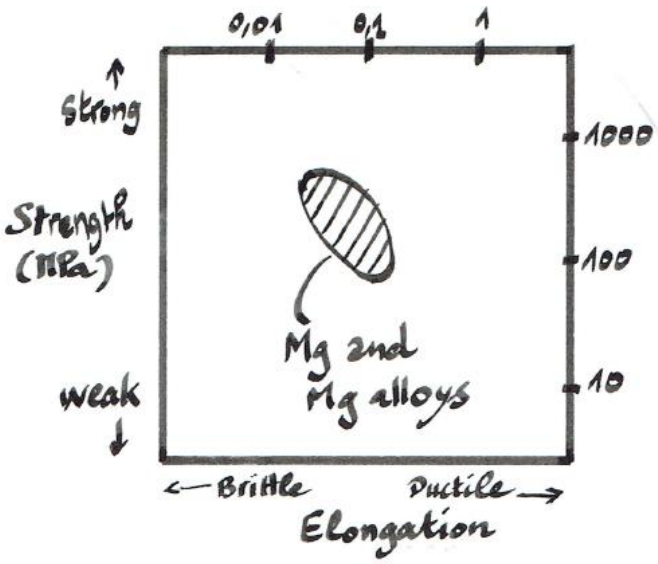

Figure 2 : Ashby diagram strength-ductility for magnesium and magnesium alloys (after [15])

This trend is clearly seen in a typical Ashby diagram (note the logarithmic scale) of Fig. 2 for magnesium metal and alloys. Thus in this example, for most of the cases, strength and ductility are antagonist, i.e. in contradiction with each other. Well, but how to express this contradiction in TRIZ terms? Let us vary one design parameter (which is itself controlled by some process parameter(s)): the grain size. The variations of strength and ductility as function of grain size are also basic knowledge for metallurgists. This can be expressed as the following couple of engineering contradictions:

EC1: If the grain size decreases, then the strength increases, but the ductility decreases

EC2: If the grain size increases, then the ductility increases, but the strength increases
The order of the "then", "but" takes into account that the materials scientist usually wants a high ductility and a high strength. This is the case, for instance:

- For the crash management of a car, where the absorbed energy is approximately related to the product of the strength and the ductility.
- For the general purpose of weight reduction.

The following physical contradiction can be derived:

PC: The grain size should be low so that strength is high, but the grain size should be high so that ductility is high.

This is qualitatively sound. However materials properties can be compared only quantitatively. Thus, if a new, developed material N is proposed, how to assess that this material is inventive relative to the state-of-the-art or just an optimization? Again in other words, how to determine whether the former PC has been overcome?

3.3. Quantitative assessment of an invention in materials science

Let us start from a material M_0, which belongs to some materials category S. Usually a specific category of materials is defined by its general composition, and by its typical properties. For instance, the category of the 2000-series aluminum alloys comprises alloys with copper as the major addition element. As an example, the famous fatigue-resistant aeronautical aluminum alloy 2024 used in the structure of aircraft wings belongs to this category. In the most general case, M_0 has a set of attributes of interest (P_1, P_2, …, P_z). It is possible that one of the attributes is related to cost (e.g. manufacturing cost per ton). Among this set most of these attributes are properties (e.g. yield stress, fracture toughness). It is assumed that:

- Any P_i (i=1 to z) can be measured as a real value in some system of units.
- The improvement of P_i corresponds to its increase; if this is not the case (e.g. cost, weight density), without any loss of generality, we may consider instead the attribute $1/P_i$. This new attribute now fulfills the necessary condition of increase.
- All the P_i are in contradiction with each other.
- In the state-of-the-art of the part of materials science that deals with S, there is a finite number of process parameters (e.g. temperature of heat treatment, weight fraction of an element) that the materials scientist can vary, so as to improve the attributes P_i. Possibly, several scenarios with the same technology are possible, and several technologies can be envisaged. Anyway the number of technologies and technology variants is finite. Then without any loss of generality the process parameters (x_1, x_2, …., x_q) are considered. Still according to the state-of-the-art, each parameter x_i can vary in a bounded interval (or sum of intervals) D_i.

Let us define the set S in the n-dimensional space (P_1, …, P_n) as follows:

$$S = \{(P_1, \ldots, P_z)(x_1, \ldots, x_q) \,/\, (x_1, \ldots, x_q) \in D_1 \text{ x } \ldots \text{ x } D_q\} \quad (1)$$

As an example, on Fig. 2 the set S of magnesium metal and alloys in the (P_1= elongation, P_2 = strength) bi-dimensional space is represented by an oblique ellipsoidal disk. Further it is assumed that S is convex in logarithmic representation, like in the Ashby diagrams for a lot of such sets of points. Let us define ∂S the boundary of S. Let us define $u(u_1,u_2,\ldots,u_z)$ the vector (still in logarithmic representation) of norm 1 ($||u||=1$) which is normal to ∂S, and external to

S, at a unique point M. Therefore it is possible to define along ∂S the vectorial function u(M). Let us now consider ∂^+S the sub-set of ∂S which is defined as follows:

$\partial^+S = \{M \in \partial S \,/\, \forall i = 1 \text{ to } z, u_i > 0\}$ (2)

It is possible to interpret:

- u(M) as the local direction of invention, for any $M \in \partial^+S$;
- ∂^+S as the set of optimized points of S.

For the sake of simplification let us illustrate the former statements with a graphical representation in 2 dimensions (cf. Fig. 3). On this Figure a new material N is positioned as inventive.

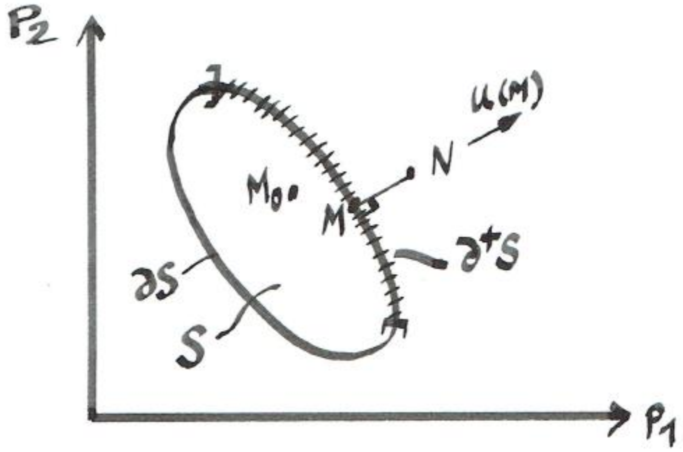

Figure 3: 2D, logarithmic representation of all the variants of a class S of materials, where ∂^+S is its subset of optimized materials (hatched curve). M_0 is the initial material.

Let us consider a new material N which has been designed beyond the state-of-the-art, i.e. some design modifications have been made which are unexpected by the specialist of the class of materials S. One is not sure whether N is inventive, because its properties could be disappointing.

Let M be a point of S which minimizes the distance between N and S. M is unique if N is external to S. Let u(M) be the local vector of invention point M. Let us define DI (where respective coordinates of N and M are $(n_1,\ldots,n_z)$ and $(m_1,\ldots,m_z)$) as follows:

$DI(N) = \overrightarrow{MN} \cdot \vec{u}(M) = \sum_{i=1}^{z}(n_i - m_i)u_i$ (3)

DI is interpreted as the degree of invention of the new material N, and it can be shown that:

- N is inventive $\Leftrightarrow \{DI > 0 \text{ and } \forall i = 1 \text{ to } z, u_i > 0\}$ (criterion for invention)
- N is optimized $\Leftrightarrow \{DI = 0 \text{ and } \forall i = 1 \text{ to } z, u_i > 0\}$
- N is not optimized $\Leftrightarrow \{DI < 0 \text{ or } \{DI \geq 0 \text{ and } \exists\, i \,/\, u_i \leq 0\}\}$

Let us name p_i the values of any point in the coordinate system $(P_1,\ldots,P_z)$ which has a logarithmic representation, then we have the relationship $p_i = Log(P_i)$ (assuming for instance that the distance equivalent to an order of magnitude in the decimal system of representation of real numbers is equal to 1, assuming the Log function is $Log_{10}(x) = ln(x)/ln(10)$). Then $n_i = Log(P_i(N))$ and $m_i = Log(P_i(M))$. Then the degree of invention of material N becomes:

$$DI(N) = Log\left[\frac{\prod_{i=1}^{z} Pi(N)^{ui}}{\prod_{i=1}^{z} Pi(M)^{ui}}\right] \quad (4)$$

In the latter equation, if necessary the right expression can possibly be multiplied by some non-dimensional constant DI°. Interestingly a link appears between DI and the equation of ideality (F/C) as defined in TRIZ, considering properties of the material instead of functions, and if one recognizes that the Pi which represents the cost is exactly 1/C (which should be increased). One notes that DI is objectively defined because the material M of comparison for N is the optimized material which is closest to N and is unique, and because the "weights" u_i are normalized. In general this degree of invention DI is intrinsic to materials (with the exception of the cost that may vary over time). DI differs from a complex parameter of system or complex parameter of ideality [16] for which the exponents are usually constant, and possibly numerically fitted, and for which the possible point of comparison is independent on N.

In the most general case of equation (4), the weights u_i vary, M varies too, and in practice ∂^+S is not accurately known. This makes the practical, numerical calculation of DI usually difficult, and therefore the determination of the inventiveness of a new material not straightforward. The precise, practical determination of ∂^+S is an inventive problem by itself, out of the scope of the present article. Nevertheless different practical approaches to estimate ∂^+S can be envisaged. In the case there are two properties P1 and P2 which are in contradiction, it is possible to approach ∂^+S by one of its tangents, then define the perpendicular vector u with constant values u_1 and u_2 in a specific Ashby diagram. Here one may note that the u_i are intrinsic to the material, while in the context of a specific application, the expression of DI might me modified accordingly. It is possible to generalize this approach to engineering systems by replacing the material properties by the levels of performance of the functions, or more generally, by the levels of performance of the MPVs (Main Parameters of Value), as suggested in [16].

Finally the degree of invention DI defined above - at the condition of strict positivity of the u_i - gives an objective quantitative measure for the inventive character of a material, and beyond for any technical invention. It is not incompatible with the level of invention (1 to 5) defined by Altshuller which is qualitative: it is actually complementary.

3.4. How contradictions are overcome in the development of new materials

Let us go back to the PC proposed in § 3.2: the grain size must be low so that the strength is high, but the grain size must be high so that the ductility is high.

TRIZ proposes several paths for the solving of this PC:

- Separation of the contradictory requirements in space:
    - PC has been overcome on a titanium alloy with the following grain structure (see Fig. 4): islands of coarse grains embedded in a matrix of ultrafine grains [17]. Indeed the coarse grains bring ductility while the ultrafine grains bring strength.

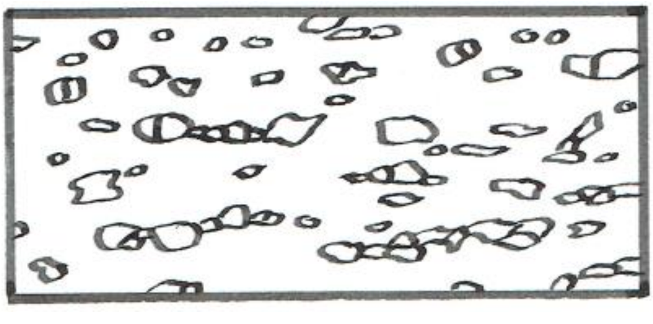

Figure 4: Schematic micrograph of a titanium alloy which is both strong and ductile: coarse grains resemble more or less agglomerated "islands" embedded in an ultrafine-grained matrix which is in white color around them (after [17])

- PC has been overcome in copper with the help of a gradient nano-grained structure: the small grains (20 nm) are at the surface while the coarse grains are in the bulk of the material [18]. This approach shows a design similarity with the cell structure of bamboos and bones [19].

Figure 5: Gradient nano-grained structure in copper (after [18])

- By satisfaction of the contradictory requirements
  - PC has been overcome in a copper alloy with nano-sized grain structure. The usual brittleness is avoided through the generation of amorphous intergranular films (AIF). This is made possible by the segregation of doping Zr atoms at the grain boundaries [20]. Mechanical properties of such alloys are shown in the Figure 6 below (note that yield strength is represented instead of ultimate strength, but this is not a real issue because a similar diagram with the ultimate strength instead would bring the same conclusions).

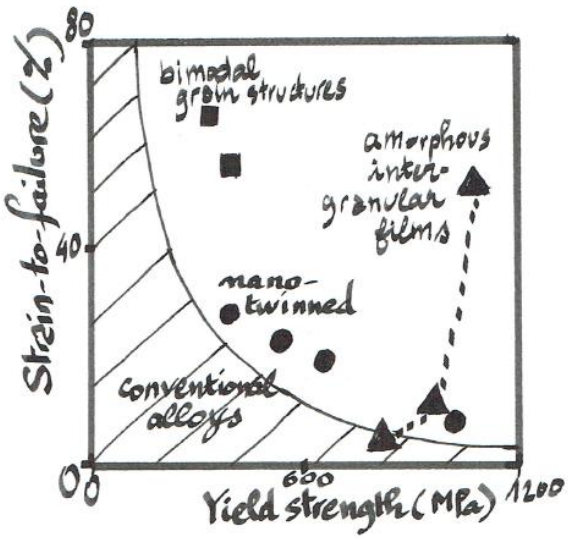

Figure 6: Ductility-yield strength diagram for different Cu-based alloys. The experimental alloys of this study are connected by a dotted line (after [20])

- PC has been overcome in a nanocrystalline 7075 aluminum alloy by precipitating nano-sized second phase particles from the aluminium matrix [21].
- PC has been overcome in an ultrafine graine copper (grain size = 400 nm) (see Fig. 7), thanks to the presence of dense twin boundaries within the grains (see Fig. 8) [22].

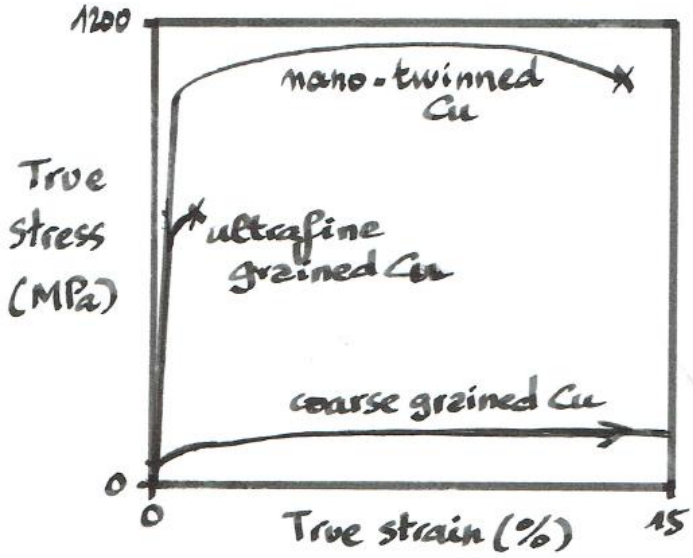

Figure 7: Stress-strain curves of coarse-grained, nanocrystalline (actually ultrafine) and nanotwinned copper (after [22])

Figure 8: Micrograph showing three ultrafine grains in copper with dense twin boundaries (after [22])

- PC has been overcome in nickel, thanks to nanodomains (which can be considered as sub-grains of the same Ni phase) created within nano-crystals [23]. According to the authors, this structural feature allows obtaining the best available yield strength-ductility known today, in a normalized diagram (see Fig. 9).

This short study is not exhausted, and on the basis of an old dilemma of materials science, the recently discovered strategies to overcome it turn out to match well the know TRIZ ways to resolve physical contradictions (separation in space, satisfaction).

In fact, many other physical contradictions arise when the materials scientist aims at developing new materials, like for instance:

- PC': The grain size should be low so that strength is high, but the grain size should be high so that electric conductivity is high [22].
- PC'': The aluminum content of low-density steel must be high so that strength is high, but the aluminum content of low-density steel must be low so that ductility is high [24].

From the former analysis which deals with some specific properties of some specific class of materials, it can be extrapolated that in the development of new materials, underlying physical contradictions relating some properties linked to some structural features are overcome by known TRIZ ways to resolve them.

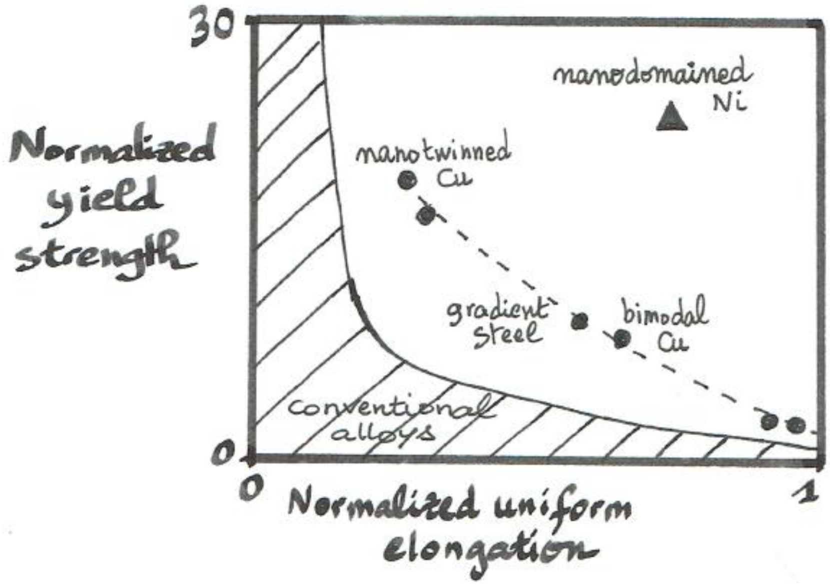

Figure 9: Normalized (yield) strength-ductility diagram for different metals and alloys (after [23])

3.5. *How to make TRIZ more instrumental for the development of new materials*

Based on the former findings, a rough program for the improvement of TRIZ for the development of new materials is proposed:

- Development of a specific database of clone problems and their typical solutions, related to contradicting properties of materials:
    - Determine typical physical contradictions that face materials scientists when developing new materials, according to the following generalized model of PC: The measure X of the structural feature should be low so that property P1 is high, but the measure X of the structural feature should be high so as to get a high property P2.
    - Search examples for the different TRIZ and structural ways these physical contradictions have been solved.
    - Classify them according to properties P1 and P2, material categories, structural features (that controlling the PC, that allowing the overcome of the PC), TRIZ ways to resolve the PC, processing principles which produce the structural feature which helps overcoming the PC.
- Further adaptation of a modern TRIZ project roadmap for the development of new materials. In particular one should consider the general alternative contradiction: The academic process A should be applied so as to enhance material properties, but the

industrial process B should be applied so as to produce large quantities and save costs. Also the concept of function must be adapted to materials which are not engineering systems in their traditional understanding and possess properties rather than fulfill functions.

This program shall be detailed and shape the basis for future research work on this topic.

4. Conclusion

In the context of materials science, the application of TRIZ for the development of new materials seems very seldom. It is believed a major cause for this lack of application is the complexity of the processing-structure-properties relationships; thus material properties are difficult to predict despite continuous improvement of models in materials science, and finally one should rely on tedious experiments. Another point is that TRIZ is adapted to engineering systems which carry functions, and materials are not systems and possess rather properties. So several major TRIZ concepts like component, function and even contradiction and invention, shall be adapted to the development of new materials.

Thus the concept of invention in materials science is addressed through qualitative and quantitative approaches. First one recognizes that a new material is inventive if a contradiction between at least two properties has been solved. Second, in the general case of several properties to improve (that are in contradiction with each other), in the frame of well-known Ashby diagrams, a criterion for invention and a degree of invention are proposed. The latter are quantitative and objective, and they are compatible with the qualitative level of invention by Altshuller, and can even be generalized to engineering systems (however the practical application of this quantitative approach gives rise to tough issues that still should be solved).

Further, considering the famous dilemma between ductility and strength in crystalline, metallic materials, a physical contradiction is proposed. Several structural strategies that the metallurgists apply to overcome this contradiction are shown to match well-known TRIZ ways to resolve physical contradictions: separation in space and satisfaction.

These novel examples encourage building a rough program for the development and adaptation of TRIZ for the development of new materials, including the systematic build-up of a specific database of clone problems connecting typical physical contradictions between two properties, the underlying TRIZ heuristics used for their solving, and the structural and corresponding processing strategies applied to overcome them.

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TRIZ IN "COPYCATTING" CULTURE

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Abstract

Twenty years of TRIZ history in South Korea accommodated the entire S-curve, from birth and childhood through growth and flowering to premature retirement. The conditions under which this history occurred are typical to multiple companies, industries, and countries. These conditions could be, in a nutshell, presented as "Copycatting Culture." In this article, the author analyses the natural mechanisms that led to premature retirement of TRIZ in South Korea, and suggests the alternative, responsible approach to TRIZ implementation into the "Copycatting Culture." Author hopes that lessons learned from experience of TRIZ implementation in South Korea could be useful to other countries, industries and companies who decide to develop "Unfair" Competitive Advantage with TRIZ.

Keywords: TRIZ, TRIZ activities, implementation, experience, learn the lessons, South Korea, Copycatting Culture, evolution, S-curve, success, competition, competitive advantage.

1. TRIZ in Korea

1.1. S-Curve of TRIZ in Korea: From Birth to Retirement

I am a lucky man. I participated in birth of TRIZ in South Korea, then in its flowering, and then in its retirement.

In 1996, LG Electronics sent the team of engineers to Ideation International Inc. The task was to reduce noise of air conditioner. Success of this project led to two conclusions of client's management: first, TRIZ is good, and second, American TRIZ is expensive. As a result, Koreans began inviting the TRIZ specialists from Russia.

In 2010, Samsung Mobile Display invited Valery Prushinskiy and I as TRIZ experts. In my opinion, this was time of flowering of TRIZ in South Korea. Fifteen TRIZ experts from Russia and USA worked at multiple companies, mostly the giants like Samsung and Posco.

Then, retirement of TRIZ came. In 2016, only three companies in South Korea use six TRIZ experts from Russia and USA; two of these companies are small businesses. On the other hand, some Universities began actively training students and engineers at Levels 1 and 2. Then, why I am talking about retirement of TRIZ?

Theory of evolution of organizations [1] says that stage of evolution (S-curve) determines the characteristics of Business. At stages S-3 (maturity) and S-4 (retirement), the main indicator stagnates, and then falls down, while the secondary indicators continue growing. What is the main indicator of TRIZ Business? Successful and profitable implementation of innovations.

Article in BusinessWeek saying that TRIZ brought Samsung substantial savings was such indicator. However, lately this indicator dropped substantially.

On the other hand, the growth of number of certified TRIZ specialists was substantial, too. In 2009, half of MATRIZ certified TRIZ specialists were Koreans; in 2015, it was two-thirds. Has it proportionally increased the innovativeness of Korean companies? Not at all. Clear sign of “retirement” stage.

Why did it happen? Why growth of TRIZ education and certification has not affected the innovativeness in South Korea? Why TRIZ in Korea, being only 20 years old, retired prematurely? I tried to analyse this issue, and now I would like to share my findings with colleagues. I hope that the lessons learned from story of TRIZ in South Korea would not waste in vain.

I do not want to say anything bad about Koreans or TRIZ experts. Both sides contributed to TRIZ success in Korea, and both sides contributed to premature TRIZ retirement. Analysis of these contributions is the topic of this article.

1.2. Supporting the Successful Innovation: Model

The model of major TRIZ activity, supporting the successful innovation, includes the main participants of this activity: Buyer, i.e. the company, industry, or country deciding to improve its innovativeness; Provider, i.e. the entity capable of supporting the successful development of innovations; and Competition, i.e. customer’s alternatives to Buyer and his products. From Provider’s point of view, Competition is Buyer’s alternative to Provider and his services.

We are going to consider, from standpoint of each participant, the lessons learned from evolution of TRIZ in Korea. Accordingly, we will consider every lesson in the following format:

- Which Buyer’s decisions could be right and wrong from point of view of efficient improvement of innovativeness?
- What should Provider deliver to the Buyer from point of view of long-term cooperation in improvement of Buyer’s innovativeness?
- What should Buyer and Provider do to outrun, outwit the Competition?

While notions of “Buyer” and “Provider” in this model are easy to understand, the notion of “Competition” is more complicated. There are three main types of Competition: competition between alternative products; competition for the same dollar in the wallet; and competition between “to buy” and “not to buy.”

The reason to consider Competition in this model is overt: Buyers use TRIZ services to develop the “unfair” competitive advantage [2] and outsmart, outrun, outwit the Competition. This is the purpose of using and implementing the TRIZ activities.

Brief comment. There are two different meanings of “unfair competitive advantage.” First is, “making something illegal to the competitors,” it is punishable by law. Second is, “doing something that competitors cannot repeat, and thus win the competitive battle,” another name of successful innovation. Although TRIZ approach could be beneficial to both kinds of unfair competitive advantage, this article considers the second meaning only. Thanks to TRIZ Master Souchkov bringing this double meaning to my attention!

From viewpoint of this model, the long-term cooperation between Buyer and Provider could work only if it is mutually profitable. Any skewness in this cooperation could drastically shorten its longevity.

1.3. Lessons Learned: Brief Overview

So far, I have managed to structure and analyse five main lessons.

First lesson is that neither side, in the end of the road, could answer the question, “Where is money?” Neither Buyer, i.e. top management of companies that implemented TRIZ services, nor Providers, i.e. TRIZ managers and specialists, were able to demonstrate improvement of revenue and profit directly attributable to TRIZ. As a result, the disbelief in ability of TRIZ to contribute to company commercial success grew rapidly.

Second lesson is that TRIZ services and deliverables should match the needs of “copycatting” culture, its current stage of evolution. Altshuller created and developed TRIZ as a tool for “creative” culture. TRIZ can support the copycatting culture, but in a very specific way. Matching TRIZ promises, services and deliverables to the current stage of evolution of copycatting culture is a difficult job for both Provider and Buyer. Mismatches cause rapidly growing misunderstanding between them, and competitors get an advantage.

Third lesson is that both Buyer and Provider should set proper Goals in order to succeed in overcoming the Competition. It sounds trivial, as many harsh lessons do. Wrong goals lead to accumulated misunderstandings and mutual mistrust.

Fourth lesson is that Buyer and Provider have different perception of Success. Both sides need to match their perceptions ahead of time. Otherwise, both are dissatisfied.

Fifth lesson is that both Buyer and Provider should invest in TRIZ activities. Otherwise, TRIZ cannot deliver, and competitors win.

Heraclitus [3] said, “You never step into the same river twice.” Unfortunately, these lessons cannot help us “restarting” TRIZ in South Korea. However, Korea is not the last country showing the interest to TRIZ. I do hope considering these lessons while implementing the TRIZ services at other countries with similar copycatting culture would be helpful in increasing the longevity of successful cooperation between Buyer and Provider.

Let us consider these lessons in more detail.

2. Five Lessons to Learn

2.1. TRIZ: Where is Money?

I start with this lesson because it is the most controversial one within TRIZ community. Altshuller created TRIZ as a tool for engineers, for solving the “technological” problems. This approach made sense in the Soviet Union, but does not make sense from general point of view. TRIZ suggestions recommend “what to think about,” and thinking cannot be limited to any specific area of human activities. However, the perception that TRIZ belongs to engineers and engineering is still alive. Moreover, some people still consider business, finances and customers as “dirt” that should not stick to the white clothes of TRIZ.

Why I am talking here about engineers and engineering? Because engineers cannot think about money. Money is something alien to engineering. It belongs to business, marketing, elsewhere, but not to engineering. As a result, question, “Where is money?” takes them by surprise.

However, this question is not any alien to TRIZ. The main job of TRIZ is solving the “unsolvable” problems and finding the solutions usually overlooked by other experts. If experts cannot find the ways to make money, TRIZ can help.

On the other hand, why TRIZ specialists should answer this question? The reason is simple. The Buyer does not buy TRIZ, rather invests in TRIZ. As a result, he expects some return on this investment, and TRIZ specialists should deliver this return. Hence, the question is reasonable.

We should start considering the ***Buyer***'s situation. Where the Buyer could find money? Only in increasing the profit. There are only two ways to increase profit: increase the revenue and reduce cost. Let us analyze each of them.

Buyer can increase revenue by improving his position in the market. One could accomplish this in five ways: increase profit, through reducing the Total Cost below the average acceptable level; increase share within the given market segment; intervene other market segments of the same market; intervene the new market; or increase size of market (volume of sales).

In order to increase profit, the Buyer should change the production paradigm. For instance, streamline the process through "reengineering" suggested by Champy and Hammer [7] in early 1990's.

To increase the share within the same segment, the Buyer should attract the customers usually served by competitors, for instance, through substantial improvement of product aspects that are currently important to customers.

To succeed in intervening the other segment, the Buyer should expand uses of his product, for example, through finding the unique opportunity to use it for satisfaction of other aspects of customers' need usually satisfied by this market. Skype used this way by offering the visual communication together with "traditional" voice.

To intervene the new market successfully, the Buyer should further expand the uses of his product through finding the unique opportunities to use it for satisfaction of other needs of customers. This is the secret of success of smartphones: they became, besides being the phones, the portable computers, audio- and video-players, navigators, and payment means.

Buyer, in order to succeed in increasing the market size, should increase volume of sales. Since number of customers in the given market is limited, one could reduce the "itching period," thus increasing the frequency of purchases. Aftermarket and market of "accompanying products" are the most prominent examples.

Cost reduction also requires detailed consideration. Each operation of business-running process creates cost in its specific way (see Figs. 1 and 2). Every way of cost creation calls for individual approach to cost reduction. For instance, "Expenses and waste of production" include, besides the obvious factors, rework, product repair, warranty replacement, reject, losses due to logistic errors, losses due to equipment maintenance and repair, quality control, etc. Each of these factors consumes time, effort, money that do not contribute to the final product. One cannot drive these factors to absolute zero, but their reduction, definitely, contributes to Buyer's profits.

From ***Competition*** standpoint, those who are "doing the same" face the similar issues. The approaches to these issues mutually accepted within the industry, country, or global market are, usually, similar. They comprise the current paradigm. The current paradigm, in its turn, determines the mutually accepted level of profitability and cost, ways to deal with customers, etc. In order to outrun, outwit the Competition, the Buyer should develop the *"unfair" competitive advantage*, i.e. the outstanding approach to improvement of revenue and reduction of costs.

Could one find any money in R&D? Naturally, yes. R&D is the source of ideas bringing the money. Buyers invest heavily in R&D in hope to receive a fat return. How to improve this ROI?

First, Buyer could reduce cost of R&D projects. Every R&D project checks feasibility of a solution to some problem. If this solution is not "the very best" one, the project team spends time, money and effort in inefficient way. If planning the R&D project starts with finding all possible solutions to the problem and selecting the most promising one, the project efficiency increases and its cost reduces.

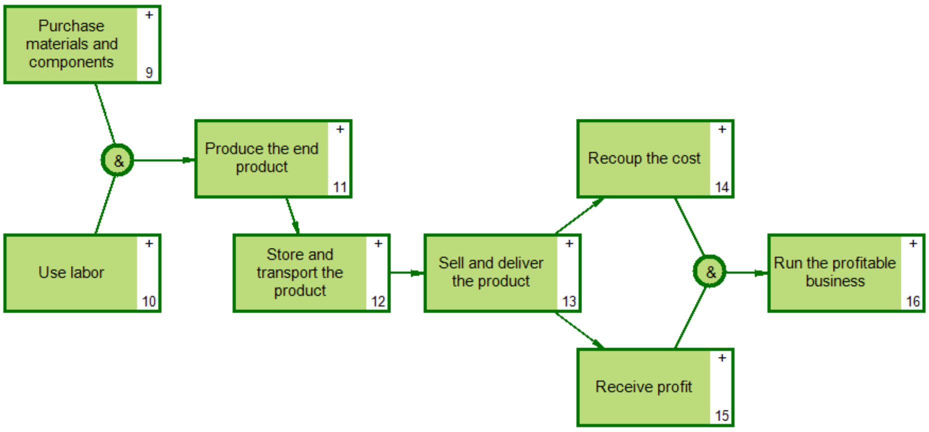

Fig. 1. Process of running the business
(Model developed with GB Pro™ Software, Guided Brainstorming LLC)

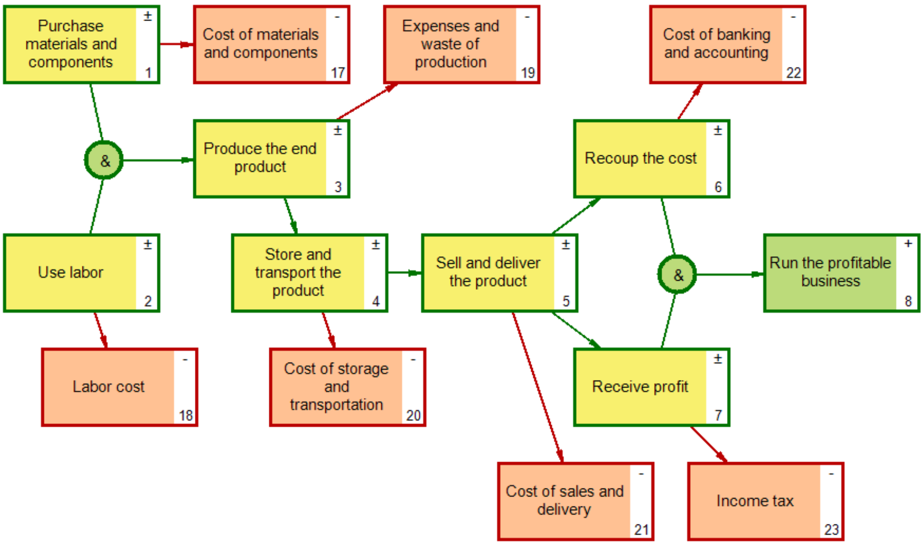

Fig. 2. Process of cost creating
(Model developed with GB Pro™ Software, Guided Brainstorming LLC)

Second, Buyer should abort the perspectiveless projects. Again, this job calls for thorough analysis of project's efficiency and consequences.

Third, Buyer needs to drive the R&D projects that promise development of *"unfair" competitive advantage* through all obstacles. Timely revealing and resolving the unsolvable problems provides for overcoming of these obstacles.

Fourth, Buyer should timely start the R&D projects results of which the Buyer would need several years later. The most prominent example of this approach is Toyota: it runs R&D projects, results of which become the core of innovations successfully implemented 10-15 years later.

Fifth, Buyer should support the R&D projects aimed at finding the new uses to the products. As a result, Buyer can launch one "core product" and then sell multiple products based on this "core."

Now, let us look at this situation from point of view of ***Provider***, TRIZ specialists. Provider should deliver the new-paradigm understanding of aspects discussed above. Is it something that we cannot do? Is it something we never did? Not at all. Finding the new-paradigm understanding is what TRIZ is doing. Then, why TRIZ people when asked, "Where is money?" look so surprised? Isn't it a psychological inertia harming the cooperation between Buyer and Provider? Isn't it a right time to overcome this psychological inertia?

Intermediate Conclusion:

In order to outrun and outwit the ***Competition***, the ***Buyer*** should aim the ***Provider***'s services (TRIZ services) at finding the new-paradigm understanding of revenue-improving and cost-reducing aspects and factors of Buyer's business.

2.2. TRIZ at Different Stages of Copycatting Culture

The trend of "Copycatting Culture" began approximately 60 years ago. Old "Production Cultures" were steadily slowing down, and new countries such as Japan, South Korea, Singapore, Israel and China, had to "catch up and overtake" them fast. The only way to do that is fast emulation of long evolution. The only tool for such emulation is copycatting.

History of Copycatting Culture in multiple countries suggests the similar stages of evolution this culture should move through (see Fig. 3).

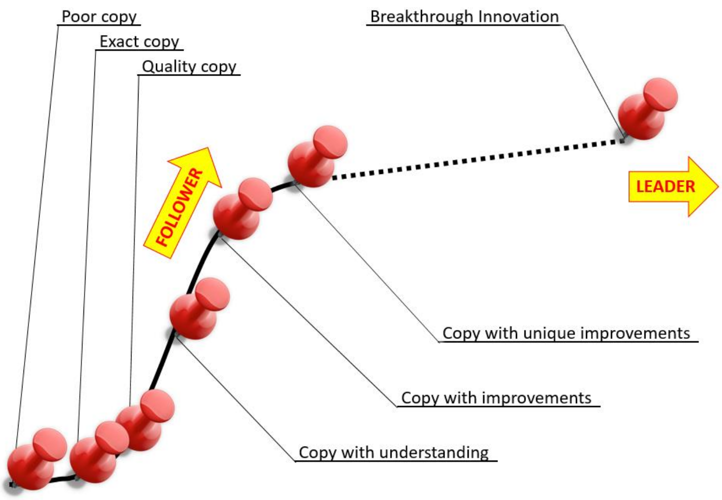

Fig. 3. Evolution of Copycatting Culture
(Len Kaplan, Presentation to Samsung TechWin executives "TRIZ for TechWin", 02/07/2015)

Each Copycatting Culture starts with vividly poor copies. Then, these copies become "exact" ones: the look exactly like original, but here the similarity ends. Later, the copies become the "quality" ones: their quality is similar to that of original. Next stage is the copy with understanding: now, the "copiers" understand the principles underlying the design of original, and use this understanding to design new products. Then, the "copiers" start improving the copies; later, these improvements become unique, overtaking the originals. At this stage, the Copycatting Culture catches up with old rivals.

The next stage should be the breakthrough innovations. At this stage, the "follower" turns into the "leader."

At each stage, the ***Buyer*** needs different kind of support from Provider, from TRIZ. Obviously, Buyer needs no support at the first two stages: poor and "exact" copies. While working on quality copy, Buyer needs the problem-solving support in revealing and eliminating the defects. "Copy with understanding" calls for problem-solving support in quality and reliability improvement. “Copy with improvement” requires problem solving aimed at improvement of functioning. Unique improvements need support in Root-Cause Analysis and development of new functions. Finally, the stage of Breakthrough Innovations calls for TRIZ forecasting.

Can ***Providers*** deliver these services? Of course, they can. What they need? They need to distinguish one stage from another, and appropriately match the support.

2.3. Setting the Right Goals for TRIZ

Goalsetting is the process of answering the right questions.

In the cooperation of Buyer with Provider (TRIZ specialist), the ***Buyer*** faces the following questions: What is the right purpose to use TRIZ? Why do I need the TRIZ specialists? Where should I aim the TRIZ efforts?

The right purpose to use TRIZ is development of “unfair” competitive advantage through solving the unsolvable problems, i.e. problems that Buyer’s experts cannot solve; these problems should be important for Buyer, and their solutions should improve Buyer’s profits. Otherwise, there is no reason to use TRIZ.

There are five types of unsolvable problems:

1. No known ways to eliminate the undesirable results or consequences of situation
2. No known ways to improve the useful result of situation
3. The Root Cause of events is unknown
4. The catastrophic consequences of decision are unpredictable
5. Emerging trends, new paradigms and successful breakthroughs are unknown

TRIZ provides for efficient help in solving these problems.

Buyer, however, needs the TRIZ specialists not for solving these problems, but rather for development of creative culture, creative community, and system of continuous professional TRIZ education.

The proper aim for TRIZ efforts is solving the key, strategically important problems. Solving these problems should help Buyer winning the competition and increasing the Return on Invested Resources (ROIR).

The ***Provider***, in his turn, thinks about the following issues: What is the reason to cooperate with Buyer? What should and what should not I do? What results should I produce?

“Making money” is not a decent reason to work for Buyer. The worthwhile goal is development of creative culture, creative community, and system of continuous professional training in TRIZ. Achieving this goal helps Buyer to evolve to the next stages, to grow, and to win the competition.

According to this goal, the TRIZ specialist could decide what to do and what to avoid doing. Both Provider and Buyer should evaluate the results of TRIZ activities against this goal, too.

From point of view of ***Competition***, both Buyer and Provider deal with other issues: How to select the proper Provider? What is the reason to set high priority to TRIZ? How to decide whether or not to use TRIZ?

Not every Provider is able to contribute to the Goal of development of creative culture and community. Buyer should use only this criterion for selection of proper Providers.

The reason to prefer TRIZ to other “creative methods” is simple: TRIZ delivers results reliably, while other creative methods do not. However, the Providers should prove this to Buyer.

Otherwise, TRIZ cannot withstand the competition with simple brainstorming-based “methods” such as Medici method.

The reason to decide if Buyer should use TRIZ is more complicated. If Buyer thinks that innovation is useless and dangerous, and problems remain unsolved because his experts are lazy, it is difficult to compete with this perception. Only the well-articulated long-term Goal could compete with lack of interest in innovations: establishing the long-lasting capabilities to reveal and implement the “unfair” competitive advantages through development of creative culture and creative team might do the miracle to Buyer’s position in the market. This should be the Provider’s unique selling proposition [4].

Intermediate Conclusion:

Both Buyer and Provider can outrun the Competition if they set the proper long-term Goal: develop the creative culture and creative community supported by continuous TRIZ education.

2.4. Success of TRIZ

The simple formula of success says,

S = R – E (Success = Result minus Expectations) (1)

It means that both Buyer and Provider contribute to success of TRIZ efforts. If Provider exaggerates or belittles the capabilities of TRIZ, if he is incapable of delivering on promises, success would not happen. On the other hand, if Buyer sets wrong goals, develops unrealistic expectations, misuses or abuses TRIZ capabilities, any Provider’s effort would not bring success, as well.

There is no reason to blame one side for lack of success: both sides participate in failure. Similarly, the credit for success belongs to both sides, too. Anyway, TRIZ specialists should analyze both success and failure: how TRIZ was sold, what we did and did not deliver, how our deliverables matched to promises; what conditions the Buyer created for TRIZ activities, which of them were favorable or hindering, how to modify these conditions next time.

TRIZ activities are successful if they contribute to both purpose and Goal. Provider should deliver to Buyer the “unfair” competitive advantage and improve Buyer’s profits. At the same time, Provider should develop the sustainable system of delivering these results; for this purpose, he should establish the creative community, creative culture, and continuous TRIZ education.

This understanding of TRIZ success means that TRIZ education should focus, primarily, on development and consolidation of practical skills rather than on knowledge transfer. Practical capabilities in solving the real-world unsolvable problems, in driving the problem-solving process to implementation, and in supporting the colleagues solving these problems, are the major criteria of evaluation of students’ success.

Intermediate Conclusion:

TRIZ activity is successful if it delivers to the Buyer promised *“unfair” competitive advantage* and establishes the sustainable system of producing new “unfair” competitive advantages. Both Buyer and Provider participate in achieving this success, as well as in failure.

2.5. Investing in TRIZ

Another formula of success says,

S = O * R * C (Success is a product of Opportunity, Resources, and Commitment) (2)

One could conclude from this formula that the most favorable Opportunity and full Commitment are not enough for success: success is impossible if no resources were invested.

It seems that an intellectual activity does not need any resources: the thoughts run in the head, what else do they need? However, as any other activity, the intellectual one needs resources. Without these resources, its results reduce or even disappear. The main resources needed for intellectual activity are infrastructure, supporting tools, working conditions, motivation, and time.

Buyer's managers, from time to time, try to "save" on resources invested in intellectual activity. The results are always the same: extinction of this activity. Never this "saving" brought any success. However, attempts to save happen over and over again, in hope that "this time, we both save money and get results." Alas, this vane hope remains such.

Infrastructure is both important and "invisible," so it is easy to "forget" it.

Any activity has specific structure of operations, aka the Underlying Process [5]. For instance, solving of unsolvable problem includes the following operations: reveal the problem; make sure that it is unsolvable; organize the team of experts for solving the problem and implementing the solution; analyze the situation; develop and evaluate the solutions, and select the "locally ideal" one, i.e. the best one "here and now"; prepare the solution for implementation; and present the solution for decision-making on implementation.

Can TRIZ expert take all these duties? Of course, he can. Nevertheless, it would be an unreasonable waste of his time and efforts. Only three operations need TRIZ knowledge and expertise: situation analysis, development of solutions, and preparation of solution for implementation. Other operations do not need such specific knowledge and expertise.

Infrastructure is necessary in order to perform these operations, in order to provide the optimal conditions for performing the TRIZ-intensive operations. The "infrastructure" means people performing these jobs, premises, equipment, etc. In addition, this infrastructure includes people who provide for necessary resources, for communication and mutual understanding, for control over the process of TRIZ services.

Interpreters or translators play important, key role in this infrastructure. Their job is to provide for efficient use of TRIZ specialists' knowledge and capabilities under condition of language barrier. Attempts to "save" on interpretation is the clear sign of irresponsible attitude to the TRIZ specialist as to the valuable resource.

The major purpose of interpretation is to improve efficiency and comfort of Buyer's experts in work with TRIZ specialist. While studying TRIZ and working in TRIZ project, they work much better in their native language. TRIZ work is intellectually intensive, and use of foreign language significantly complicates it.

Supporting tools include books, software, websites, etc. These tools are important for education and efficient work of TRIZ community, knowledge transfer, qualification improvement, etc.

The "***working conditions***" are not limited to the table in the cubicle, computer and phone. These conditions include conditions for thinking and meetings, conditions for mental relaxation, living conditions with minimum problems, conditions for communication with colleagues, conditions for search for information and knowledge, conditions for TRIZ research and experiments. If Buyer does not provide for these conditions, TRIZ specialist's efficiency drops dramatically. Saving on these conditions does not pay off.

Why do we need ***motivation***? TRIZ community is a small army attacking the unknown. As any army, this one needs bright uniform, shiny decorations, euphoria of parades. Without this, one should not expect any victories, whole-hearted loyalty, or relentless around-the-clock intellectual efforts. Buyer trying to save on motivation demonstrates disloyalty and disrespect to TRIZ specialists. Since loyalty and respect are two-way roads, why should such Buyer expect loyalty and respect in return?

Here is a vivid example of proper motivation and support of TRIZ. Mr. Cheong SeHo, then the TRIZ adviser of CEO at Samsung Mobile Display, talks about his experience in times of TRIZ flowering in Korea [6]:

Mr. SeHo Cheong from Samsung told his personal story of TRIZ learning mixed with the Samsung company story in a very effective way, starting with his trip to Russia in 1999 to hire TRIZ experts.

He showed us a great variety of case studies, starting in 2001, with washing machines, refrigerator door design, and the whole development cycle of the OLED product family. Some early case studies were considered significant because they persuaded senior management to support TRIZ, and some are significant because they gave Samsung early market dominance in their fields. Now in all product development reviews, engineers are asked if they use resources, if they focus on major contradictions, if they have a concept for future super systems and sub-systems, and other TRIZ-based questions. Since they know the questions will be asked, they use TRIZ extensively in development. In SMD (Samsung Mobile Display) only 9% of projects were defect improvement projects; the majority were new products, or processes for creating the new products. Mr. Cheong offered several lessons from experience:

1. Verification is important. Verify new ideas immediately. Waiting kills creativity

2. Top-down project selection is very important. This protects projects from getting cancelled early.

3. Select people for the “Creative elite” (internal TRIZ promotion and education team) who have both the technical ability and the personality to help other people succeed.

4. Use a task force for big projects, with the project team and the TRIZ team as partners, dividing the work.

The Samsung teams use a very basic flowchart, with many tools of TRIZ/ARIZ/OTSM used where appropriate for the specific project. There was considerable interest by the audience in the training system, and particularly in the note that the CEO had graduated from the basic level class! The TRIZ training is accompanied by a support system of consultants and patent writing advisors. A TRIZ Festival is held annually. Last year (2009 – LK) the 12 best of 62 projects were selected, and 7 awards were given, to promote TRIZ. Samsung has an internal “webzine” and a conference for their own TRIZ association (6 of the Samsung companies share their experiences.) Future plans are to develop a broad base of projects (not just top-down), to increase the number of people with higher-level tools, to modify tools and methods for business problems, and to continuously improve the effectiveness of the education and support systems.

Intermediate Conclusion:

In order to win the ***Competition***, the ***Buyer*** should invest in TRIZ activities, and create the optimal conditions for Provider. The ***Provider*** should respond to this investment with maximum effort in achievement of mutually accepted Goal.

3. Implementation of TRIZ

Neither Buyer nor Provider should leave the implementation of TRIZ services to chance. The implementation should take care of many unobvious issues. Otherwise, implementation fails, and TRIZ service cannot deliver efficiently.

Many things pretending to be TRIZ, actually, are not. Not everybody pretending to be TRIZ specialist is such. Not everybody who says he can do that and that using TRIZ, actually, can. It seems overt, but usually it is not. How could this understanding start working?

Contemporary TRIZ comprises multiple different versions. Different TRIZ specialists present the same version in different ways. How could the Buyer decide which versions to implement? I am talking about several versions worth implementing, because the "only true" version of TRIZ does not exist. Variety of versions is useful for further development and improvement. However, not every version of TRIZ is worth using and implementing. Only "artificial selection" based on specified criteria could help the decision-maker to make a proper choice.

Let us assume for a moment that somebody already suggested criteria for evaluation of results of TRIZ specialist's activities, and both Buyers and TRIZ community accepted them. Buyers should evaluate the results rather than people, TRIZ specialists. Evaluation of results is more objective than evaluation of people.

Then, we need to suggest the procedure for such evaluation and distribution of best practices.

Of course, this procedure should start with development of criteria. TRIZ specialists should know these criteria from the very beginning. Moreover, they might participate in development and improvement of these criteria, because they do know what they can and what they cannot produce.

On the other hand, TRIZ specialists who feel that they cannot meet these requirements have a choice: refuse to do the job; try to achieve the required results; or at the beginning tell the Buyer about personal limitations. In this case, the Buyer can decide what to do: continue searching for "ideal" TRIZ specialist or accept this one and support him with other specialists who could compensate for his weaknesses.

In any case, "you do the job, and then we decide how to evaluate it" is inacceptable approach. It means the "moving target," no results can satisfy the permanently changing criteria. Today, the Buyer wants you to find any solutions of this problem; tomorrow, he says that you should not solve this problem because some manager is offended; next, it comes out that you solved this problem "in the wrong way" – anyway, you are bad, and nobody needs your results… Is it my paranoid fantasy? Better, ask any TRIZ practitioner. It is a reality, bad reality.

Next step of procedure is a limited, local test of capabilities of chosen version of TRIZ and selected TRIZ specialist. It should be really local, contained within one entity or even one location, and, at the start, within one project. Then, TRIZ specialist can concentrate his efforts on achieving the necessary results rather than dispersing the efforts "a little bit here, a little bit there." Only if efforts are concentrated on one job, TRIZ specialist could achieve substantial results.

Next step is monitoring of TRIZ specialist's activities. One should not expect quick results, but the positive dynamics, growth of results should be demonstrated. For this purpose, TRIZ specialist should report his results annually. If 2-3 years do not show the growth, the Buyer should find out what happened.

This situation is not simple. Many different problems could contribute to this failure.

First, it might occur that TRIZ specialist cannot produce needed results. TRIZ specialists are just humans, with limited abilities. Second, it might happen that Buyer's managers do not support or even hinder the TRIZ specialist's activities. Third reason for such failure might be the resistance of Buyer's experts to changes suggested by TRIZ specialist. In any case, Buyer should find out the Root Causes of problem and then decide how to deal with it.

Buyer should evaluate the results against the criteria after longer period, probably, after 3-5 years. This is a different type of evaluation. In this case, Buyer evaluates the results, not their dynamics: what TRIZ specialist managed to achieve, what he could not, and why. Here, Buyer should find out the real Root Causes of each discrepancy between criteria and results, and suggest the ways to improve the situation. This improvement, again, takes time, maybe, couple of years. Buyer should monitor this process and check its dynamics.

After this procedure, the Buyer should make decision: whether or not wider distribution of this experience makes sense.

If Buyer decided to expand the successful TRIZ experience, implementation of this decision should be evolutionary, not revolutionary. One TRIZ specialist who succeeded in small scale cannot repeat this success at large scale. First, he should prepare people who will do the job in new locations.

Naturally, this preparation should start during the “local” implementation of TRIZ activities. However, this preparation should end up in independent work of new TRIZ specialist, under supervision of his trainer. This “traineeship” takes time, maybe, 2 or 3 years. Those who succeed in traineeship are ready to unaided work.

Through this evolutionary procedure, Buyer forms several “growth centers” thus expanding TRIZ activities onto entire Buyer’s sphere of influence: company, industry, or entire country.

Buyer should not consider these “growth centers” as competitors. He should not compare their results or hold up one center as an example to others. Such internal competition might hinder TRIZ activity rather than accelerate and improve it. The activities of these centers should “compete” only with criteria they should meet. Quite opposite, these centers should exchange their successes and experiences on the permanent base. They should communicate openly. Any “secrecy” between these centers always hinder their results.

This is the brief description of flawless procedure of implementation of TRIZ activity.

4. Conclusions

The purpose of TRIZ implementation is development of “unfair” competitive advantage. The long-term Goal of TRIZ implementation is development of creative culture, creative community, and continuous TRIZ education. In this way, Buyer receives the sustainable system of developing the “unfair” competitive advantages. When both sides, Buyer and Provider, pursue this Goal, TRIZ delivers on its purpose and helps outrunning the Competition. When both sides abandon this Goal and start pursuing other goals, TRIZ retires prematurely, and Competitors win.

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TRIZ MATURITY EVALUATION IN ORGANIZATIONS

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Abstract

In nowadays, more and more organizations are introducing TRIZ to enhance their innovation capabilities. However, lots of efforts faltered due to improper deployment strategies. This paper gives some suggestions for promoting TRIZ in the organization. The guidance is a table with criteria, such as leadership support, resource allocation, TRIZ project management, TRIZ knowledge system and so on. Each item has a score. The higher total score the organization can get, more likely of TRIZ will be successful.

Keywords: TRIZ maturity, deployment strategies, guidelines

1. Introduction

TRIZ has becoming more and more popular in many organizations. In many world leading companies, such as Samsung, General Electric, POSCO, etc., TRIZ has become an engineering culture and generated a lot of solid results and as well as profits. The application of TRIZ has also expanded to many areas, such as solving technical problems, patent circumvention, technology forecasting…

With the expectation of promising pay back, more and more organizations are investing money on TRIZ training, consulting and trying to build the culture in their organization. However, many high level managers of the organizations are confused that their efforts didn't gain success, since they got very few solid results. Compare with the investment of funding, time and energy, TRIZ didn't generate enough results as they expected. Through the experience of successful TRIZ promotion in NICE(National Institute of low-Carbon and clean Energy), Shenhua Group, and the studied from the experience of the most successful TRIZ organizations, physical company visits, discussions with the key promoters and the consultants who led the TRIZ efforts in those organizations, some guidelines were developed. The guidelines can either give advice to those organizations who want to implement TRIZ in their organizations or being used to evaluate the maturity of TRIZ in their organizations.

NICE started TRIZ from zero since 2013. In each year, there are more than MATRIZ Level 1 certification training sessions. From 2014, there is one MATRIZ Level 2 certification training session. Level 3 training is in progress. Totally, there are 150 engineers took MATRIZ Level 1 training and 60 engineers got MATRIZ Level 2 certificates. Now, TRIZ is very popular in engineering teams and it has generated a lot of solid results. Gradually, TRIZ has become an engineering culture of NICE. Look back the path of NICE TRIZ culture building and I can feel the biggest challenges that hindered the promotion of TRIZ are not TRIZ methodology itself. Most barriers are non-technical factors and they contributed 90% of TRIZ failure. Therefore, how to break the non-technical barriers are very important for TRIZ success in the organizations.

2. Guidelines

The guideline evaluates the TRIZ maturity from several main criteria with points. Below each main criterion, there are sub-criteria. You can get the total score of each criterion. Add the score together, and then you can get the total score. The full score is 1000 points. Based on the total score, we can measure the TRIZ maturity (or success) in that organization.

The guidelines evaluate the maturity from different aspects, such as TRIZ Positioning, Leadership Support, Resource Allocation, Promotion Strategies, Management Process, Methodology, Project Management, Promotion Team, Incentive, Results and Demonstration, Level of Satisfaction, Level of Application, etc.

3. Details of maturity criteria

1.1 Strategic positioning: How the organization position TRIZ (50 points)

- 1.1.1 The organization position TRIZ as the main methodology for technology innovation
- 1.1.2 The organization has the vision of making TRIZ as their engineering culture
- 1.1.3 The organization has the policies of deploying TRIZ

1.2 Leadership support: TRIZ promotion can’t be successful if the management level fight against it, therefore, leadership support is very important. (100 points)

- 1.2.1 The leadership should support TRIZ not only verbally, but also practically. There should be evidence that the top leadership supports TRIZ activities organization
- 1.2.2 The leadership should review TRIZ activities and monitor the progresses continuously. Monthly TRIZ review is highly recommended.
- 1.2.3 The top leaders have already taken necessary TRIZ training (at least one day, the longer the better)
- 1.2.4 Leadership helps to remove the key barriers
- 1.2.5 Leadership approve the TRIZ goal for the whole organization
- 1.2.6 The level of the people that lead TRIZ activities, normally TRIZ activities report directly to the technology related VP, or Director of administration. Normally, he or she should directly report to CEO.

1.3 Resource allocation. Necessary resources are needed for the TRIZ deployment. If there is no resource, it is almost impossible that TRIZ can be success in the organization. (50 points)

- 1.3.1 The organization provides enough funding for TRIZ deployment.
- 1.3.2 The organization provides necessary time for TRIZ activities
- 1.3.3 The organization has internal TRIZ specialists to support TRIZ activities
- 1.3.4 External resources. TRIZ consultant that the organization uses for TRIZ deployment. We strongly recommend the world well known experienced TRIZ experts.

1.4 TRIZ team. It is necessary to build a professional TRIZ team to lead the activities. The TRIZ team will be in charge almost everything related to TRIZ deployment.

TRIZ team is extremely important for the TRIZ success.(100 points)

1.4.1 The organization has full time, professional internal TRIZ specialists (TRIZ leader). We don't recommend part time internal TRIZ leader. He might not have enough time and energy to commit.

1.4.2 Job position of the internal TRIZ leader(The level is the higher the better, normally directly report to technology related VP)

1.4.3 TRIZ level of the internal TRIZ leader (TRIZ level is the higher the better, strongly suggest the TRIZ leader is MATRIZ Level 3 or higher certified)

1.4.4 Soft skills of the internal TRIZ leader. The internal TRIZ leader should have soft skills, such as influencing skills, communication skills… to solve the non-technical problems.

1.4.5 The organization has formed or appointed TRIZ team and the team should be well trained. Normally identified through the trainings, TRIZ projects facilitations and the other TRIZ activities.

1.4.6 Skills of solving real problems. The TRIZ team should have the capabilities of solving problems without the help of external consultant. Normally, internal TRIZ team need to learn how to solve problems and facilitate problem solving after they learned from external experts.

1.4.7 TRIZ team suggest reasonable TRIZ goal of the year to leadership

1.4.8 TRIZ team has clear goal and the goal is count into performance

1.4.9 TRIZ team has clear career path in the organization

1.5 Deployment strategies. From the most failures of TRIZ deployment in organizations, we found the failures are not because of TRIZ methodology, leadership support or lack of resources. They are because of promotion strategies. (100 points)

1.5.1 The organization has actionable deployment strategies

1.5.2 The organization has clear step-by-step near, middle and long term plan of deploying TRIZ, with milestones.

1.5.3 The organization should have a TRIZ goal and this goal should be top-down broken down to all eligible employees(normally engineers with engineering problems)

1.5.4 TRIZ deployment should focus on project execution and generating solid results other than training only

1.6 TRIZ methodology. 60 years passed since TRIZ was developed. It kept changing especially in the past 30 years. Those changes made TRIZ more powerful.(150 points)

1.6.1 Integrity of TRIZ methodology. It should include problem identification, problem solving and solution substantiation. Not only problem solving tools.

1.6.2 Problem identification tools should include but not limited to function analysis, cause effect chain analysis and trimming

1.6.3 Problem solving tools should include but limited to inventive principles, standard solutions and ARIZ.

1.6.4 Novelty of TRIZ methodology. Besides the classical TRIZ(developed by Genrich Altshuller himself and his disciples from the mid-1950s to the mid-1980s) , it should also include the modern TRIZ tools developed since perestroika in the former Soviet Union (from the mid-1980s to present)

1.6.5 Organization introduces TRIZ level by level. (recommend follow MATRIZ 3 levels knowledge requirements)

1.7 Project management process. Solving the problems from the projects is the purpose of most organizations why they introduce TRIZ. It should be the core of TRIZ activities in the organization. Every other TRIZ activities should serve this “core” (100 points)

1.7.1 The organization should have management processes of project definition, project approval, project execution, project closure and project transfer.

1.7.2 In each stage of the process above, there should be clear purpose and guidelines. The results should be documented.

1.7.3 In each phase, there should be decision makers to make the right decision to ensure the TRIZ project is on the right track.

1.7.4 Recommend TRIZ be integrated with the other project management processes, such as Stage-Gate, IPD, DFSS…

1.7.5 TRIZ project should include problem background and the source of the project. Ensure TRIZ work do the right things.

1.7.6 TRIZ project should be a part of an ongoing R&D project or it is closely related to the goal of the organization.

1.7.7 There are quantitative criteria for project evaluation.

1.7.8 The project evaluation should include but not limited to project rationality of project selection, correctness of TRIZ tools utilization, desired project goal achievement, solid results achieved with TRIZ (patents, measureable results, paper publication, feedback from management), team work and quality of the report, etc.

1.8 Results and demonstration If there are too few solid results, the continuity can’t be guaranteed. Sooner or later, TRIZ will diminish. Continuous results generation helps to build and maintain the culture of the organization. (150 points)

1.8.1 TRIZ projects generate solid results

1.8.2 TRIZ results are reflected with financial number or the other measurable or non-measurable indexes, such as quality improvement, competitiveness improvement or market share increase…

1.8.3 The results could be implemented solutions that solve the problems

1.8.4 The results could be patents application or paper publication

1.8.5 The results should be communicated among the organization

1.8.6 Recommend TRIZ team organizes internal contest or TRIZ project team participate the external contest

1.9 Incentive. Incentive is necessary especially at the beginning of TRIZ promotion. (50 points)

1.9.1 Organization should recognize the TRIZ achievements

1.9.2 Organization should give awards to the excellent TRIZ project and those who has contribution to TRIZ

1.9.3 Organization should recognize the team or projects who get the awards, either internal awards or external awards)

1.10 Employee satisfaction (Employees' satisfaction is a symbol of TRIZ culture. Only the employees satisfied, TRIZ culture can persist) (100 points)

1.10.1 There should be a TRIZ satisfaction survey among the organization, normally once a year

1.10.2 TRIZ satisfaction should be reflected with measurable score. The score is the higher the better

1.10.3 The survey results should be analyze to identify the gaps and problems in employees' mind

1.10.4 The results should reported to the leadership and be communicated in the organization and answer the questions aroused from the survey

1.10.5 Actions should be taken for the problems identified in the survey

1.11 Level of TRIZ application. Modern TRIZ could be used in different ways based on different combinations of different TRIZ tools. Based on the actual conditions of the organization, TRIZ could be used for different purposes (50 points)

1.11.1 Level of target problems TRIZ applied on. Industrial level, company level or project level

1.11.2 Percentage of TRIZ users in all employees

1.11.3 Functions that are using TRIZ. Research, Development, Engineering, manufacturing… The more the better.

1.11.4 The organization tried to promote TRIZ in supply chain

1.11.5 TRIZ application expanded to different stages of problem solving, problem identification, problem solving, patent generation/circumvention, technology forecast… The more the better.

4. Summary

This paper developed a tool for evaluating TRIZ maturity the organization. It can also serve as a check list of TRIZ promotion. It may give you some inspirations of how to make your TRIZ work better. These criteria are mostly from my experience of TRIZ promotion in NICE. Behind each criterion, there are stories to support it. However, it is far not enough to cover all aspects. In order to make it more perfect, suggestions are welcomed.

Don't expect your organization can get high score if you promoted TRIZ for very short time or with very little effort. If you can see the score is higher year by year, you are on the right direction towards TRIZ success in your organization.

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TRIZ INNOVATION COURSE FOR ADOLESCENTS IN SHANGHAI

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Abstract

Shanghai is one of the most developed areas in China, and provides the highest standard of conventional education in the country. In PISA2012 (Program for International Student Assessment), which assessed the capabilities of middle school students of 64 countries and regions, the mathematical, reading and scientific capabilities of Shanghai junior middle school students ranked the highest. In this context, I started to offer an innovation course at several middle schools in Shanghai from 2012. This course is designed according to the physiological characteristics, knowledge structure and cognitive level of students of two age groups, one from the 3rd to the 6th grades (8-12 years old) and the other from the 9th to the 11th grades (15-17 years old). Aiming at maximizing students' innovation ability, the course comprises three parts: creative works appreciation, innovation knowledge teaching and group discussion. I have been offered the innovation course for 4 years and achievements have been gained. Most importantly, this course has brought fun to students and improved their knowledge and innovative thinking ability.

Keywords: TRIZ, innovation education, creativity, adolescents innovation

1. Design of TRIZ innovation courses for adolescents

Théodule-Armand Ribot, the famous French psychologist, in his Essay on the Creative Imagination, shows that the peak of human creative imagination occurs between 14 and 16 years of age [1] [5]. Then the curve begins to drop. That was in the beginning of the 20th century. Now a hundred year after Ribot, the peak of creativity is much lower and the peak age has shifted to between 10 and 12 years (Figure 1). After that, with the increase of age and life experience, the creativity decreases gradually and finally reaches a very low level. The decrease in creativity is mainly attributed to the psychological inertia caused by the burden of knowledge and experience. The more knowledge and experience one has, the less creative he/she is.

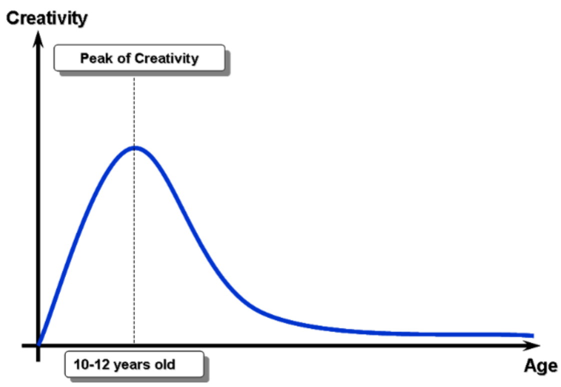

Fig.1 Human creativity curve

Adolescents are at the creativity peak stage proposed by Ribot. They are highly imaginative and characterized by leaping and divergent thinking. On the other hand, they are learning a variety of scientific knowledge systematically. Therefore, it is necessary to help them maintain their creativity while they are learning knowledge. This is the purpose of the TRIZ innovation course for adolescents. The course is designed to acquaint adolescents with the innovation process and help them develop innovative thinking. Figure 2 shows that by learning innovative methods, people's ability to create will increase continuously with age [1].

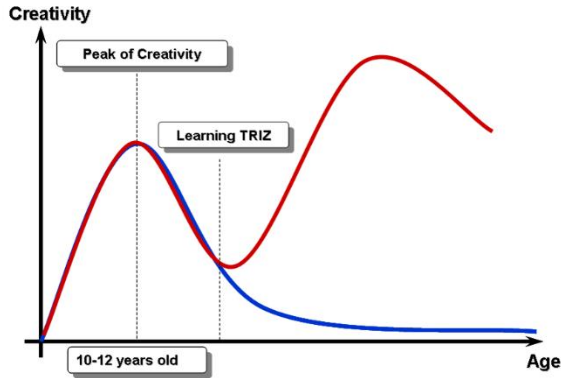

Fig.2 Continuous increase of human creativity

The advantage of TRIZ lies in that it integrates methods, knowledge and thinking systematically to help users achieve innovation. TRIZ can effectively avoid the negative effects of knowledge and experience in the process of innovation. Moreover, it can improve people's imagination and creativity by making use of their knowledge and experience. Adolescents and adults are very different in knowledge level, life experience, level of thinking and many other aspects. That is why TRIZ training for adolescents is completely different from that for adults in arrangement, curriculum design and teaching methods. In addition, as adolescents are in the process of learning knowledge, the TRIZ innovation course for them does not go beyond what they learn, and the thinking training is designed according to their cognitive level. What's more, exercises are designed to be interesting and entertaining.

The TRIZ innovation course for adolescents is delivered in forms of games and exercises. First, the teacher instructs students to understand and differentiate things from an innovation perspective and use these skills to analyze objects and phenomena. Then students are required to do divergent thinking exercises which are designed to broaden their imagination. Finally, the teacher acquaints students with the innovation process and teaches them to solve innovation problems step by step in a structured way. Such an arrangement can effectively improve adolescents' creative thinking ability and standardize their way of doing things. This course can help students invent gizmos and gadgets. More importantly, by taking the course, students will develop a set of scientific and rigorous problem-solving approaches, which can be applied not only in technology development but also in daily life and learning activities.

2. Practices of the TRIZ innovation course for adolescents

In the first half of 2012, Shanghai College of Science and Technology, which is sponsored by Shanghai Association for Science & Technology (SAST), initiated a series of innovation education activities for adolescents. SAST enjoys comprehensive advantages in training, as it cooperates with a large number of experts in various disciplines. Benefiting from these advantages, Shanghai College of Science and Technology launched the Innovation Seed Program for Adolescents to help young people make the most of their creativity peak stage. Within the framework of the program, the TRIZ innovation course has been designed for primary and secondary students in Shanghai. Jointly promoted by SAST and the Huangpu

District Education Bureau of Shanghai, this course has implanted the seed of innovation in adolescents and attracted a great number of young people to join the grand cause of building China into an innovative country.

The TRIZ innovation course for adolescents aims to improve their creative thinking ability and help them master certain innovation methods so that their creativity can be maintained while their knowledge and experience accumulate. It is my hope that this courses will inspire the innovative potential of young people, improve their hands-on skills and enhance their self-confidence.

Since the second half of 2012, Shanghai College of Science and Technology has arranged to offer the TRIZ innovation course for adolescents at several primary and secondary schools in Shanghai every year. This course covers the basic knowledge of TRIZ and gives priority to training students' thinking process, helping them control the direction of their thoughts and inspiring their creativity. It is delivered in forms of teacher explaining, exercises, group brainstorming and results release.

Training of the thinking process: Adolescents have active but sometimes rambling thoughts. As a course in thinking, the TRIZ innovation course for adolescents teaches students how to use their creativity and how to control their thoughts to be divergent or convergent in time of need. To this end, I designed a set of thinking training forms, which are the main thread of the course. These forms require students to follow fixed formats in understanding, deconstructing and comparing objects, as well as in diverging their thoughts and applying the ideas derived from divergent thinking. With the help of the forms, students can gradually regulate their thinking habits and adapt themselves to innovation. With the proceeding of the course, the forms go from the easy to the difficult, echoing with each other and becoming more and more comprehensive and rigorous.

Controlling of the direction of thoughts: Adolescents are characterized by high creativity and divergent thinking, but they cannot control their thoughts well and tend to think aimlessly and unlimitedly. However, innovative thinking should be target-oriented and bounded by certain boundaries. Only when a person gears his/her thoughts toward innovation, can he/she gain positive results. By taking the TRIZ innovation course, young people will understand their thinking process and learn to control their thoughts. They will also learn how to understand objects from different perspectives, when to diverge their thoughts and when to stop divergent thinking. Finally, they will find applicable innovative solutions.

Inspiration of creativity: In the TRIZ innovation course for adolescents, innovative pictures and videos are shown to acquaint students with the latest achievements in innovation. During this process, students are required to analyze and discuss how creative ideas are generated. In this way, the innovation knowledge and thinking process taught to the students can be solidified. The course also requires students to set up innovation targets by observing life carefully and try to achieve the targets by using TRIZ. The purpose of doing so is to make the course closer to life, take students experiencing the innovation process (especially the innovative thinking process), inspire their creativity and strengthen the innovative thinking process for them. By taking the course, students can not only invent gizmos and gadgets, but also create literature works, compile stories, draw paintings and do stage shows. Therefore, the TRIZ innovation course has positive effects on all aspects of young people's life. When I offered the course to some junior school students, I divided them into several groups and asked each group to design an outing by brainstorming. The starting point of creation was a lightened incandescent bulb. From the light emitted by the bulb, the students thought of dark places and thus designed caving, camping and bonfire night activities; from the shape of the bulb, they thought of ballooning; from the electricity used by the bulb, they thought of playing laser war games.

3. Outcomes of the TRIZ innovation course for adolescents

Since the year of 2012, I have offered the TRIZ innovation course for adolescents for nearly 5 years. During these years, more than 300 students have taken the course and completed more than 40 works of innovation, among which an innovative solution won the first prize in the Adolescents Innovation Competition in Shanghai. Winning prizes is not the only target of the course. It mainly aims to arouse students' interest in innovation and improve their creativity. It has been proved that the creativity of students who took the course has been improved more or less.

In 2012, I offered the innovation course to some 6th-grade students. One day, I asked them to do an exercise of replacing system objects. After discussion, a group of students released their ideas to the class. They conceived an umbrella with an air surface. The other students in the class thought the idea impractical and laughed at it. But it was actually a good idea. A Korean designer had proposed a similar design. When those students learned that someone else had thought of a similar idea, they were not disappointed. On the contrary, they were very happy and became more confident.

In another 6th-grade class, a student was very fond of fishing. His fingers were once hurt by a fishing hook. Therefore, he wanted to invent a safety hook. I gave him some instruction and guidance on this. Eventually he focused on the sharp end of the hook. He described the physical contradiction of this component as follows: a fishing hook should have a sharp end to catch fish; a fishing hook should not have a sharp end so as not to hurt people. By applying the separation principles, he worked out several innovative solutions and drew schematics of these solutions. For a student at this age, this was really a great achievement. But for elder students, the requirements are higher. A student of the 10th grade wanted to invent a pair of eyeglasses with lenses of variable thickness for his myopic and presbyopic grandfather. He soon focused on the lenses and described the physical contradiction of the component: the lenses should be both convex and concave. In order to solve this contradiction, he searched for information on the Internet and found an applicable scientific principle. Then, according to the scientific principle, he drew a structure diagram for the new type of eyeglasses. Now he is preparing to make a prototype and wishes to submit it as an entry to the National Youth Innovation Competition.

The TRIZ innovation course has changed adolescents' understanding of things around them, made them more positive toward life, and helped them generate interesting ideas. Before they took the course, heavy homework assignments deprived them of time and energy for imagining freely. According to a survey by SAST, only less than a third of the 6th-grade students in Shanghai have ever thought of fantastic or ingenious ideas; and more than 60% are willing to innovate but they have no time to think about what to do and their thinking has never been opened up. 85% of the students who finished the TRIZ innovation course said that the course improved their thinking ability and creativity; and 80% of them said they would like to continue learning the course. Commenting on the TRIZ innovation course for adolescents, Li Jiwen, headmaster of Xinling Primary School, said, “Kids today have very few opportunities to receive innovation education and even fewer opportunities to communicate with innovation experts, so they enjoy very much in taking this innovation course. Knowledge that our students cannot learn at school is taught in the course. We all love this practical and extraordinary course."

4. Conclusion

As a powerful tool for innovation, TRIZ helps people achieve innovation quickly and efficiently. Not only adults but also adolescents need to learn the theory. Adolescence is a critical period for learning knowledge, fostering creativity and developing life values. During this period, we should strengthen science education activities so as to arouse young people’s curiosity and desire for knowledge, improve their ability of applying basic science knowledge, deepen their understanding of themselves and things around them, acquaint them with scientific thinking and methods necessary for scientific exploration, and help them develop a life attitude of being harmony with nature. All of those will exert direct influences on the career development and life values of adolescents. Targeting young people at the peak stage of creativity, the TRIZ innovation course for adolescents aims to improve their creativity and creative thinking ability and help them master innovation methods, so that their creativity can keep increasing with age.

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TRIZ INTEGRATION FOR PROJECT MANAGERS – DISCOVERING FURTHER TRIZ BENEFITS

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Abstract

This article describes learning experiences to integrate TRIZ methodology in a company not only into the general product development or DFSS processes but in an alternative way.

It describes valuable ways for TRIZ implementation by project managers, using the common product life cycle (PLC) and its processes and tools. In the range of the PLC a lot of different departments and people are connected via the structured processes and toolsets of the PLC under the lead of a project manager. This offers great opportunities to use and implement TRIZ for several reasons. At the one hand there is already an accepted methodical framework to which distinct TRIZ-tools can be added smoothly and at the other hand a widespread range of practitioners is addressed over the PLC – so there is no need for highly specified and sophisticated training sessions.

The article reflects these and other advantages as well as disadvantages of the TRIZ-integration by the PLC-project manager in comparison with the integration into regular or advanced product development processes, e.g. DFSS. After this description of the benefits by integrating TRIZ in PLC as part of work of the project manager, the article corroborates this by some illustrations of successful examples of TRIZ integration at the company Continental Automotive GmbH.

Keywords:

TRIZ, teaching, learning, integration, project manager, PLC, methodology, successful implementation, DFSS

1. Introduction

1.1. Definition and Process of a PLC

To explain the background for this paper, first it is necessary to define and describe some major elements and tools which are used in the automotive industries as standard.

The abbreviation PLC stands for Product Life Cycle. The PLC describes the whole life of a product. It starts with an idea which has a chance to be placed on the market. During the development this idea will be converted to a final product. This product has to pass the industrialisation phase to start successful in serial production. Later in the product life cycle, the customer demand decreases, the product reaches the after sales market and then the recycling stage. Considering the trends of evolution and with the understanding of the S-curve in mind, it can start again as “new” product [1] in an improved and advanced version or maybe as a completely new successor product. That’s why it is called a cycle. One of the benefits of the PLC-thinking is the large toolbox available for the different phases to optimize the value add for the product itself. Also the PLC provides detailed process descriptions that enable project managers to guide the product through an optimal process with an optimal value add. The gates included in the PLC ensure the quality and the expected achievements in the given timeframe. So the product leads to economic success for the company.

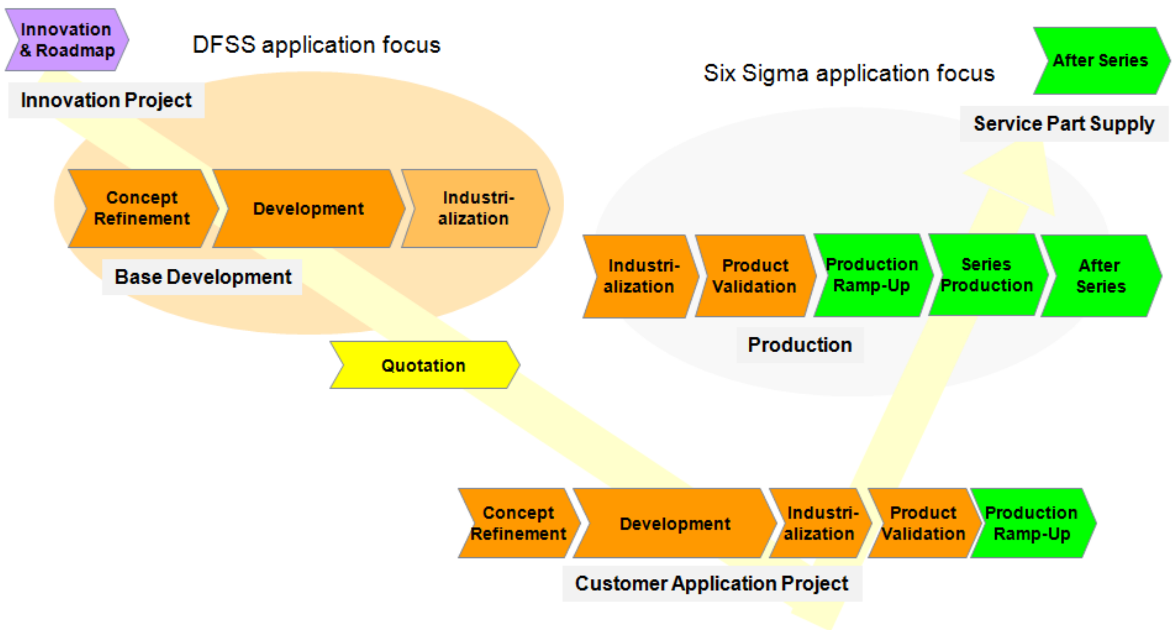

Fig. 1PLC @ Continental [2]

1.2. Project manager

The term “project manager” has various meanings and responsibilities – these vary from company to company. So it is difficult to have a common understanding about a project manager, if this role is not defined in the particular context. This part of the paper in based on the general role of project managers at Continental. The project manager is responsible for the realization of the economic success of his or her dedicated product or product family by using the PLC. He or she gets the responsibility to lead the whole project team, to support and also to train the team with all available tools from the PLC-toolbox. This is given to empower the project team to finish all requested tasks of the PLC under self-responsibility.

Project managers have to support the team work and to coordinate all the activities which are described in the “process house”. The PLC is part of this process house. Due to process orientated organisation the project manager gets access to experts and resources of all disciplines inside the organisation, to use it with the project team. He or she has to take care of the losses and profits of the project and is responsible for the reporting of the project progress to the product line management. There are also various more detailed role descriptions existing, which contain more detailed tasks and responsibilities. But for this article, the aspects listed above explain the role sufficiently.

2. Introduction of TRIZ within new product development and DFSS

In general in Continental the integration of TRIZ in the DFSS-methodology is intended and appreciated. The table shows a summary of key reasons for usage of TRIZ in Continental.

Table: key reasons for TRIZ together with DFSS @Continental

key reasons	used in DFSS	used in TRIZ
early implementation during development	x	x
use of methodological approach	x	x
use of structure elements	x	x
use during development supports high value add	x	x
working with different standard tools	x	x
working with models	x	x
working with patents in the development	x	x
using physical / technical parameters	x	x
using guidelines or standards	x	x

Also further arguments can be found which are demonstrating a very fertile ground for using TRIZ in a company especially starting in an environment of product development and DFSS. The integration of TRIZ and Design for SixSigma (DFSS) is also conducted by many other companies and consultants, see e.g. [3], [4], [5], [7].

3. Alternative ways to implement TRIZ

One of the tasks of project managers is to empower the team and to support it with trainings to achieve the requested targets of the project. So a project manager has good overviews of the team skills. A problem-related usage of TRIZ tools can be initiated here directly with the team – without the need, to train a complete department or business area with a huge TRIZ-toolset overall and in advance. It is possible to feed selected TRIZ-tools accordingly to the stages of the project and to the appropriate needs. The PLC and the linked tasks give clear indications of needs for the project manager to use the different tools for shaping and guiding the project. So an implementation of TRIZ is possible directly within the planning of the different work packages. It can be introduced cooperatively with the team into the standard processes to clarify the tasks given by the project. Also in the course of a project various possibilities may occur to identify alternative ways for the implementation of TRIZ-tools.

- For example a team has a long term task which is going into direction of a critical time line: here to have a refreshed start using TRIZ-tools can be very helpful (e.g. using resource checklists and procedures to strive to ideality, see e.g. [8], [9]).

- Another way for the integration of TRIZ-tools can be identified at each stage of the project when it comes to a critical step or a problem. The 8D process in such a case is a useful framework to include some TRIZ-tools. For example cause-and-effect chains (CECA) and TRIZ problem formulation (see e.g. [10]) help to clarify the problem. Typically the formulation of technical contradictions helps creating good countermeasures. Anticipatory Failure Determination (AFD, see e.g. [11]) helps to find and eliminate root-causes of even wicked problems.

- At the development stage the formulation of physical contradictions (see e.g. [9]) is very helpful, when size tolerances and other tolerances have to be defined. This fastens the discussion and decision regarding setting tolerances enormously and gives room for creative ideas – in contrast to linear methods as e.g. the 5-why.

- Each project has a lessons learned task, a chance to use ARIZ-85b part 7-9 (see e.g. [9]) to get not only a comprehensive list of findings and actions before closing the project.

- Furthermore the lessons learned can be enriched by the function analysis (see e.g. [12]). Especially the differentiation between harmful and useful functions and the evaluation of useful functions as being insufficient, normal or excessive leads to a very visual and logical overview of the success of the project and possibly next projects. Regarding the motivation of the team members the function analysis at this stage emphasizes the relevance of TRIZ – they recognize the achievements of the actual project and also the deviation of future project that will also include working with TRIZ-tools.

These examples give some idea, how TRIZ-tools can be integrated in the PLC. Each PLC-task, -phase or project gate can be used to integrate further helpful TRIZ-tools (see fig. 2).

4. Support of ways to implement TRIZ by the project manager

A project manager should also take over the role of a mentor or a trainer for the team in terms of using TRIZ-tools at the right time in the right way. He or she can anticipate activities to be done in the different project sessions, prepare the usage of TRIZ-tools and motivate the team for these methodological approaches. Also he or she may develop the training contents for team members to learn TRIZ together with the team and based on its needs. He or she can support the dissemination of TRIZ in the company by reporting the successes and lessons learned to the team and to the management. So the project manager acts as a multiplier for TRIZ in the whole organisation.

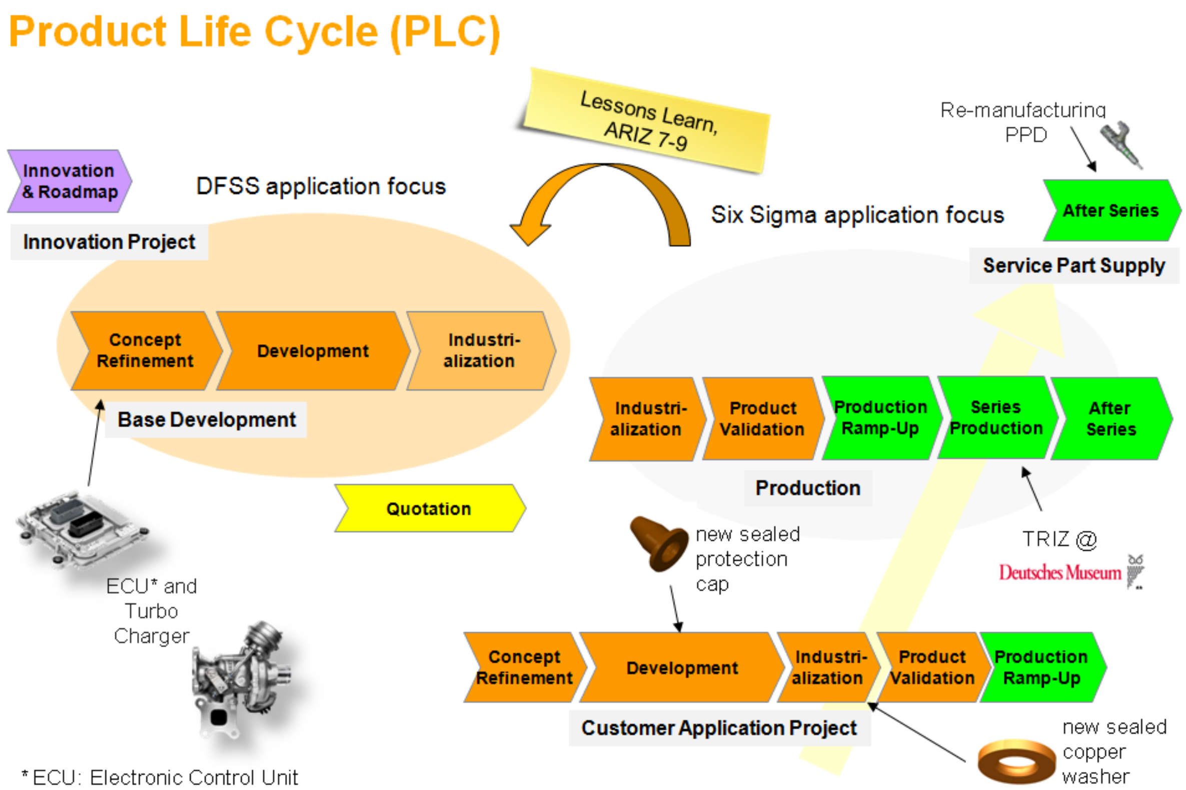

Fig. 2 TRIZ examples in the PLC @ Continental [6]

Figure 2 shows some examples of TRIZ projects which are identified, trained and implemented with project management in Continental. It should demonstrate the various possibilities to integrate TRIZ completely in the existing process house of the company without adapting anything of the PLC-system itself.

So in terms of MATRIZ certification, project managers should be internal TRIZ-specialists at about the MATRIZ Level 3. Project managers normally use to lead and develop trainings on several topics and have good facilitation skills. So project managers have the ability and the responsibility to train the team all the way – there will be no turf war.

Besides the personal role of the project managers, the company has to document the work with TRIZ-tools and the results. This documentation should be stored in databases, so future project managers are able to look at earlier applications and results. Usually a useful file structure already exists (e.g. according to the PLC- and/or DFSS-stages) and may be used also to store the TRIZ-usage documentation.

But this article emphasizes, that the TRIZ-integration should not be fixed and determined in the PLC in form of new checklists, new gates or new obligatory tasks or processes. The decision about using or not-using some TRIZ-tools should stay with the project manager. He or she and the team keep control about their workflow and their choice of supporting methods – based on their experiences and needs.

5. Conclusions and Perspectives

Project management stimulates the application of TRIZ by “real life” topics in a project in different ways and different situations. It supports a harmonization of learning and working with TRIZ at the same time. Project management opens a wide field for TRIZ implementation next to the well known ways like the formal integration to DFSS or new product development processes. In addition the project manager as a trainer and mentor of TRIZ is a helpful instrument to support an efficient implementation of TRIZ in a company. At Continental it will be used and combined with the aspects to install also training courses for employees together with project management support.

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TRIZ PRACTICE IN THE CREATIVE CAREER EDUCATION BY THE COOPERATION OF KINDERGARTEN, ELEMENTARY SCHOOL, JUNIOR-HIGH SCHOOL AND NATIONAL COLLEGE OF TECHNOLOGY

-APPLICATION OF 3D BLOCK TO CREATIVE EDUCATION-

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Abstract

As training of the industrial human resource which bears the future of the area, creative career education from low age is desired. Mental faculties, such as capability to compare, contrast and analyse and the capability to find and combine the relation and law of things are required for especially in "creative activities", and the five conditions for the activity are said to be (1) Low age, (2) Setting up of the environment, (3) Maximize children's ability, (4) Giving freedom, and (5) Helping them. Authors have developed educational contents which use 3D block of ArTec Co. Ltd as a tool of creative education. The unique characteristic of this item is on the the point that one can turn what one has in mind into actual figures since it can be assembled to three dimensions (up-and-down, front and rear, right and left, slant). This paper describes the validity of the example to the creative education using 3D block as an application of TRIZ to conquest binary oppositions comparing the measure by cooperation of Kindergarten, Elementary School, Junior-high school and National College of Technology with the Reggio Emilia method famous for early childhood education.

Keywords: Creative education, 3D Block, Kindergarten, Elementary school, Junior-high school, National College of Technology, ArTec Co., LTD

1. Introduction

Nikitin, who advanced an intellectual education of children, recited and practiced that as for the "Practical activities" human resources required concentration, memorization, ability to repeat they had seen and heard, ability to manage almost systematically while as for "the Creative activities" ability to think themselves and find solutions. In particular, he insisted that the mental faculties to compare, contrast and analyze as well as the ability to find and combine the relation and law of things were essential for the creative activities. The five essential elements required in this activity are (1) Low age, (2) Setting up of the environment, (3) Maximize children's ability, (4) Giving freedom, (5) Helping them. In this context, the representative of the practical training for the development of intellectual creativity is "a Block play"[1]. Authors have developed educational contents which use 3D block of ArTec Co. Ltd as a new tool of creative education which is suitable to the culture of Japan. The unique characteristic of this item is on the point that one can turn what one has in mind into actual figures since it can be assembled to three dimensions (up-and-down, front and rear, right and left, slant). There is a very famous method for infantile education called Reggio Emilia Approach. What makes it very revolutionary while being one of the biggest reasons why this approach receives much attention from those who engaged in infantile education world-wide is "the Overcoming of binary oppositions". Moreover, the very distinctive characteristics of this method lie on the practical approaches such as "the Spiral circularity", the idea of repeatedly experience under the same theme but through different approaches, as well as "the Variation of the subject", to express invisible concepts and ideas by different measures to visualize what they have in mind. This paper describes the case studies of the creative career education utilizing the characteristic of the community. On this occasion, in order to achieve "the Overcoming of binary oppositions", the following elements were focused. "Art and Science" to have relationship with the science and technology in the regional industry, “Child and Adult" to work as a team, namely Team Shiroko, regardless of ages or grades, "Enjoyment and Study" 1. to create an electrical car using 3D block and challenge a car race at the Suzuka Circuit, 2. to conduct an experiment using a Pill bug robot made by 3D blocks. In the relevant studies, the TRIZ was practiced mainly by the students of the National College of Technology and discovered to be very effective in the problem solving in accordance with the stages of the development of children.

2. Experimental method

2.1. 3D block

The representative of the practical training for the development of intellectual creativity is a Block play. Authors have developed educational contents which use 3D block of ArTec Co., Ltd as a tool of creative education which is suitable for the culture of Japan. In Japan, there is a background of the 3D concepts such as building of houses by using and combining wood materials, which was expected to be effective in developing creativity by building and combining blocks in 3D (up-down, front-back, left-right and slant directions). Moreover, the conception and creativity were brought up in the state-of-art technology in each era. In the flow of times, branches and wooden blocks in the time of the wood, stone implement in the time of the stones, clay and earthenware in the time of the soil and bronze as well as ironware in the time of irons. Today, in the time of oil, plastic is the technology of the state and it is the reason why3D block is considered to be effective.

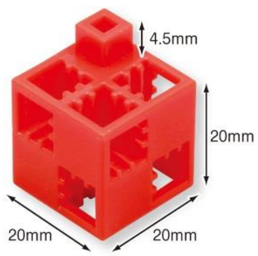

Fig.1. 3D block

Fig.2. Activity in Kindergarten

2.2. Team Shiroko

The creative education using 3D blocks was applied on the cooperation of the Kindergarten, the elementary school, the junior high school and the Technical College (hereafter referred as the Team Shiroko of totaling 120 people consisting of 40 infants, 20 grade-schoolers, 30 junior high students, 40 students from the Technical College). Team Shiroko is existed in the Shiroko district in the city of Suzuka, Mie Prefecture, where the core industries of the area are the automotive and agriculture. It is in a favorable environment to achieve the career education from the infantile education such as the good cooperation with the local community and having the kindergarten and elementary school being adjacent.

Fig.3. Activities of Team Shiroko

2.4. Reggio Emiria method

There is a very famous method for infantile education called the Reggio Emila Approach. One of the main reasons this practical method is considered to be very revolutionary receiving attention from those who engage in the infantile education world-wide is in the Overcoming of binary oppositions. Moreover, the unique characteristics of this method are also said to be in such practices as the Spiral circularity and the Variation of the subject. In this paper, the application examples of the creation type career education utilizing the characteristics of the local communities are described.

2.5. Application of TRIZ to overcoming binary oppositions comparing

In the trials with Team Shiroko, the following comparative elements for the overcoming of the binary oppositions were experienced. In "Art and Science" to have relations with the science and technology in the regional industry. In "Child and Adult" to work as a team, namely Team Shiroko, regardless of ages or grades. In "Enjoyment and Study" 1. to create an electrical car using 3D block and challenge a car race at Suzuka Circuit. 2. to conduct an experiment using a Pill bug robot using 3D blocks. This is where the TRIZ education works as the key solution. In "Small family and big family", the participation of the three generations was achieved as a family education at such locations as Suzuka Circuit etc. The examples of the practical effort for "the Spiral circularity" are the Suzuka Terrace, an open space located in the shopping street in front of Shiroko station where students in Suzuka National College teaches how to play with 3D blocks directly to small children, and also the road map of the creative education listed as Fig.6. As for the practice of "the Variation of the subject" to visualize what cannot be seen 3D blocks were used to shape what they had in mind to perform movement, control, experience and challenge. The purpose is to encourage them to describe about what cannot be observed visually since the most interesting idea and theory is believed to come from it.

3. TRIZ application experience results and consideration

TRIZ was practiced by the students of National College of Technology and discovered to be effective in the problem solution according to the stage of the children's growth. (1) Application to electric car in 3D block. How do they keep running in Suzuka Circuit without dropping the blocks? (2) Education of importance of life with Pill bug robot. How is it achieved to teach infants the character of the alternate conversion reaction?

3.1. Application to 3D block car

There is the problem of 3D block car. How is the body built? Can shape be made with the block? Is the block attached for the body well? Does the block drop? What can be done with the weight?

Example: The problem about the body "It wants strength though I want to change shape freely". In this context, by using the contradiction matrix the following principles of Innovation are derived. The property to be improved is 32 Easiness of Production and the deteriorated property was 14 Strength.

#1. Principle of division →3D block application and body division structure. #3. Principle of local quality →Device of the way of assembly of 3D block. #10. Principle of preliminary action →New parts are made in 3D block. #32. Principle of use of color→Reinforcement of transparency (tape and film wrap preparation).

Fig.4 shows the 3D block car jointed the race at the Suzuka Circuit. Fig.5 shows the examples of the creative education in accordance with the respective age. Fig.6 is the road map of the relevant activities which shows that there are opportunities to join activities in the local community in accordance with the respective age.

Fig.4. 3D block car

Fig.5. Examples of spiral circulative practice

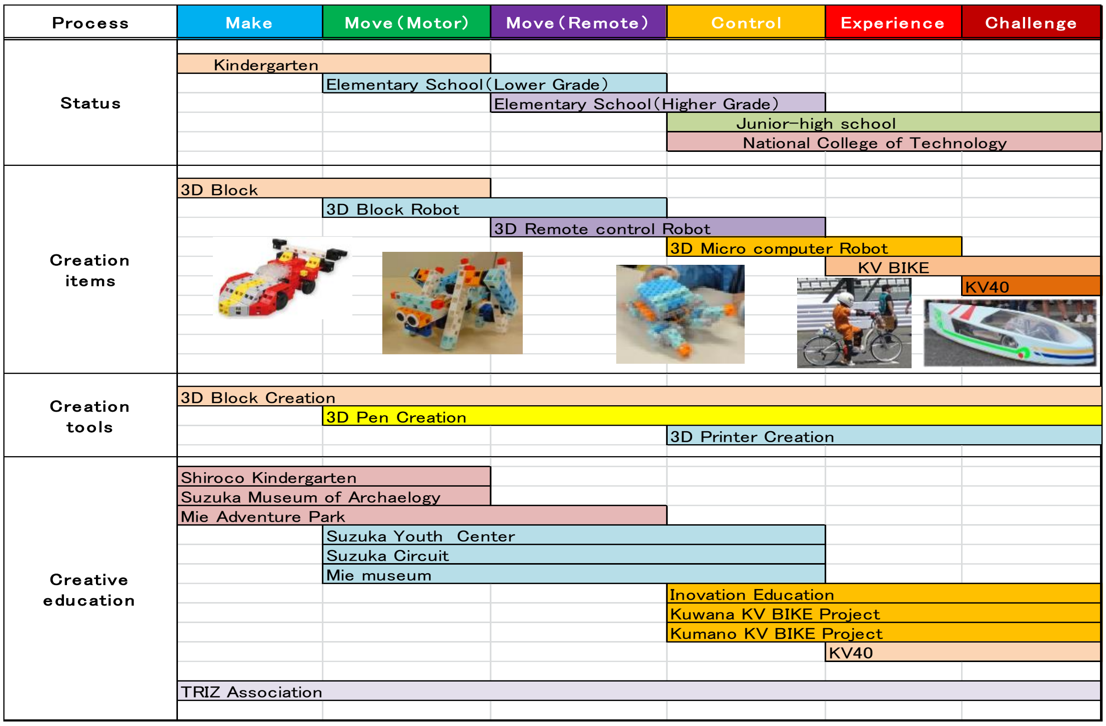

Fig.6. Roadmap of spiral circulative practice

3.2. Experiment of Pill bug

The purpose is to have kindergarteners learn the alternate conversion reaction of Pill bug. In order to conduct the experiment, the maze made of the 3D block was used. The experiment went well when it was accomplished only with the Technical College student. However, it did not work in the experiment with the kindergartner. Many of the bill bugs stopped showing the alternate conversion reaction due to the stress caused by the environmental change and also being touched by the kindergarteners. Moreover, there was even individual which was died of the stress.

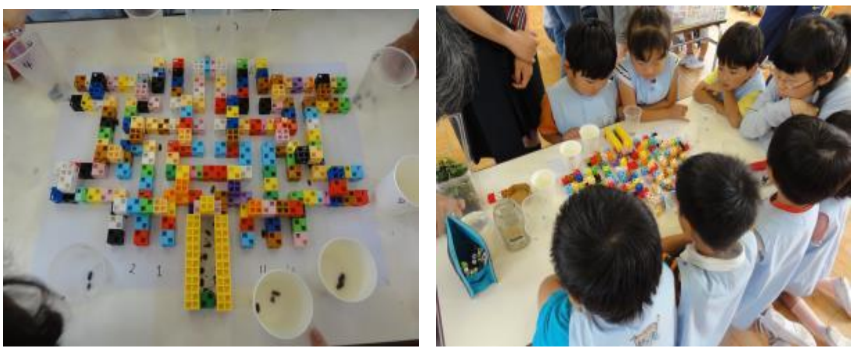

Fig.7 Experiment of Pill bug

Table1. Experiment results of Pill bug

①Result of going with kindergarten lives											
Goal	1	2	3	4	5	6	7	8	9	10	11
Number of rolly pollies	5	10	6	15	2	2	1	11	15	5	9

②It is only a Technical College student and original is a result of going in the quiet surrounding.											
Goal	1	2	3	4	5	6	7	8	9	10	11
Number of rolly pollies	0	2	1	36	0	0	0	31	0	3	0

There was an individual which died of the stress caused by the changes in the surrounding environment and also by being touched by the kindergarteners. In this context, the solution was examined to decrease the number of the death of sample Pill bugs.

<Contradiction matrix> As the improvement of the success rate of the experiment on the alternate conversion reaction is desired, it was determined that the item to be improved is the reliability. Since it calls for the preparation of the environment appropriate for the experiment and also the settlement of the children, the deteriorated item was determined to be the complexity of the control.

<Principle of invention> #27, in the idea of longevity replaced from short longevity that is cheaper than something expensive and long life, it is simply achieved by adopting something lifeless inherently. #40, the replacement of the sample to a robot was considered under the concept of utilizing different materials on the basis of the idea of the use of the composite materials. #28, in the idea of replacement from the replacement of a mechanical technique to a technological, electric, magnetic place, the Pill bug robot can be easily made by making the robot from composite materials with combining 3D blocks. As a result of the considerations, use of the Pill bug Robot was decided along with the use of living samples. Pill bug Robot was 15cm being installed with the contact sensor and it was programmed to show the alternate conversion reaction. After having experienced with the Pill bug robot to acquire the basic knowledge, there was no sample found dead in the experiment with the kindergarteners.

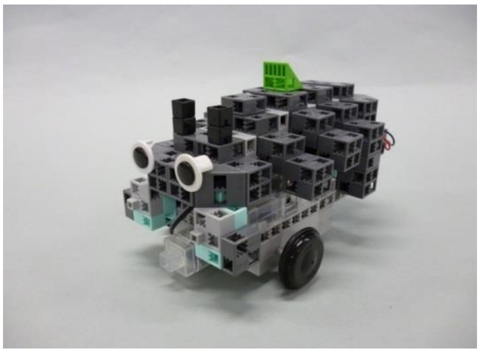


Fig.8 Experiment with Pill bug robot

4. Conclusions

As practices of the TRIZ in the creation type career education with the cooperation of the of the kindergarten, the elementary school, the junior high school, and the high school, the following points were clarified through the application of the 3D blocks to the creative educations.

1. In the binary oppositions of Art and Science can be accomplished by having the relation with the science and technology in the local industry while Child and Adult can be overcome by the joint effort as Team Shiroko.

2. The application of the TRIZ together with the use of 3D blocks to the creation type career education with the cooperation among the kindergarten, the elementary school, the junior high school, and the high school is very effective in the binary oppositions of the Enjoyment and Study as validated with (1) the Prize for the design given to the challenge with the 3D car to the Suzuka Circuit and (2) the Highest Award to the experiment with the Pill Bug Robot.

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TRIZ-ORIENTED APPLICATION OF INNOVATIVE METHODS AND CONSTRUCTION OF COLLABORATIVE INNOVATION SYSTEM

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Abstract

Nowadays, Innovation has been crucial competitive advantage in business and technology, how to build and develop the capacity of innovation is the primary issue to implement the innovation strategy. Pearl River Delta of Guangdong province is the worldwide famous manufacturing center, there are a lot of companies of high-tech industry and numerous minor enterprises of traditional manufacturing industry, they have pressing demand of transformation and upgrading by innovation. Being the well-known advanced innovative theory, TRIZ has developed many reliable and effective tools for promotion of technology innovation. This paper introduces the efforts of Guangdong province on application and spreading of innovative methods in recent years, including training program of TRIZ, practical application of TRIZ and other innovative methods in companies, research work of innovative methods, innovative-related works in university and college, etc. By evaluating the achievement of these efforts and current activities of innovation, this paper sums up some reliable ways to promote innovation practice, analyzes some problems and difficulties of innovation, puts forward a proposal to construct collaborative innovation system combining with enterprise, academic institution, university and government. Meanwhile, with case study of some innovation practices, it is indicated that the collaborative innovation system has made significant improvement in the promotion of application of innovative methods including TRIZ and enhanced the performance of innovation practice.

Keywords: TRIZ, innovation, inventive methodology

1. Introduction

TRIZ has a long history, it has become a powerful tool to solve technic problem and to create inventive solution. But TRIZ is a new thing in China, it was introduced to China only about twenty years. In the last ten years, an increasing number of people have learnt TRIZ. China's TRIZ workers have made a lot of efforts to promote and apply TRIZ, and those works are fruitful. In different regions of China, the application and development of TRIZ have different characteristics. This paper introduces some achievements of TRIZ in Guangdong province, points out some problems and describes some future works to develop TRIZ in Guangdong.

1.1. Earlier History of TRIZ in China

Before nineteen nineties of last century, TRIZ was not known in China. At the late of the 1990s, TRIZ was introduced to China 0. In the early spreading of TRIZ in China, Innovation Method Society played a major role to introduce TRIZ in China.0. At first, TRIZ was known by some researchers, technic specialist and university teachers, they learnt and studied TRIZ as a kind of new method, attempted to solve problems in their works with TRIZ. Those problem are mainly concentrated in machinery industry, such as mechanical design and manufacturing.

In July 2007, three senior academicians of Chinese Academy of Science wrote a letter to then Prime Minister Wen Jiabao，they made an strong appeal to Premier Wen that it was urgent to enhance the national innovative capability of China, Prime Minister Wen made a rapid reply to them and made some important instructions 0. Since then, four government branches including Ministry of Science and Technology, Ministry of Education, National Development and Reform Committee, Chinese Technology Association have been responsible to implement the plan and process. In Oct 2007, the Chinese government has accorded great importance to innovative methods, and TRIZ has been widely spreading in China 0.

1.2. Introducing TRIZ in Guangdong

In 2009, according to government’s plan to enhance works related to innovative methods, Guangdong province was approved as a pilot to comprehensively promote the application of innovative methods including TRIZ0. After several years of continuous efforts, TRIZ has been gradually spread in Guangdong, more and more people have put attention on TRIZ and made a lot works of TRIZ on teaching, training and application.

2. TRIZ in Guangdong

2.1. Network of promoting TRIZ in Guangdong

From 1978, with its unique political economy advantages and geographical location, Guangdong province has been in the front of reform and opening-up practice in China. In the past thirty years, Guangdong has achieved tremendous economic and social development. Nowadays, Guangdong is one of the most developed area of China, its Pearl River Delta is the worldwide famous manufacturing center and export powerhouse, there are a lot of companies of high-tech industry and numerous minor enterprises of traditional manufacturing industry0. Guangzhou and Shenzhen, two of four first-tier cities of China are located in Pearl River Delta, many global companies have set their branches in Guangzhou and Shenzhen, some local leading enterprises are headquartered in Shenzhen and Guangzhou, there are pressing demand of Industrial upgrading and technological innovation.

In order to maintain the leading position in the economic development and technological improvement, Guangdong must attach great importance to cultivation of innovative methods. Being the well-known advanced innovative theory, TRIZ has been get a better promotion and application in Guangdong. Since 2009, a hierarchical network has been built to promote TRIZ in Guangdong, it is shown in Fig.1

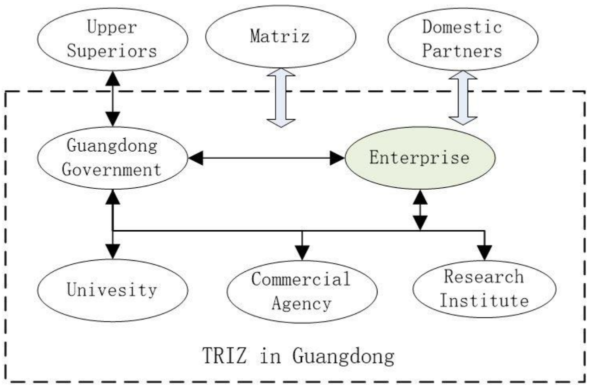

Fig 1. Hierarchical Network

2.2. Current Situation of TRIZ Transmission in Guangdong

As shown in Fig.1, the promotion and application of innovative methods based on TRIZ has some unique characteristics of Guangdong.

Dedicated to reginal development strategy and industrial innovation, as the sponsor of innovation, the government has positively communicated and collaborated with many companies, universities, science research institutes, science and technology service agents, so as to provide a working platform for all participants and establish collaborative system with enterprises as the core that combine “production, learn, research and service”, the cooperation mechanism of network is effective and efficient in work of promoting TRIZ0. During this period, the definite change is that enterprises gradually became the main strength of application of TRIZ from recipient to driving force.

The hierarchical network mainly has three internal level, external superiors and external cooperative partners, they play different roles and complete different job. The cooperative mechanism and its operation is shown in Fig.2

2.3. Achievement of Promoting TRIZ in Guangdong

1. Social awareness

To attach the state media and local press coverage, to report activities and achievement of innovative methods, to introduce the knowledge of TRIZ, to promote the awareness of TRIZ among the public, to enhance the reputation of innovative methods. The interest to TRIZ and practical requirement of TRIZ have increased by upper practice. TRIZ is gradually recognized by the public and enterprises0.

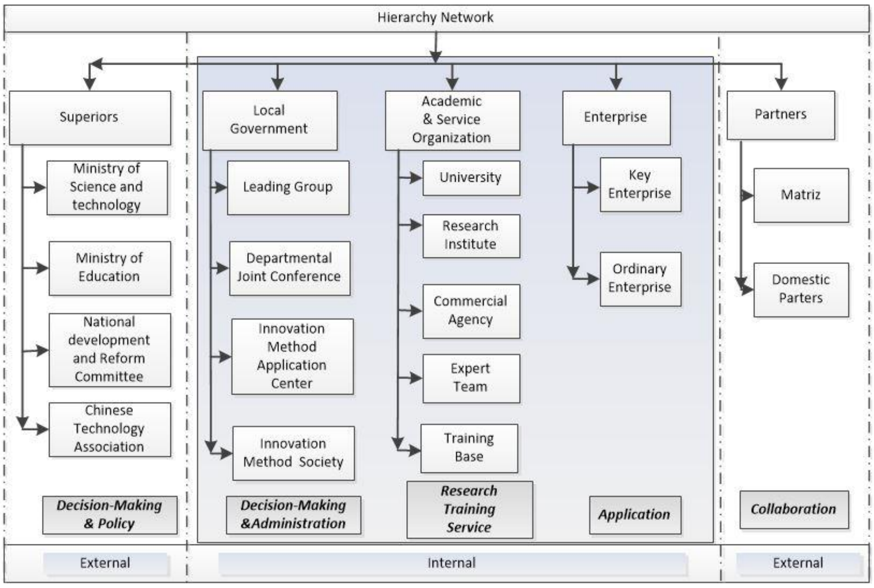

Fig 2. Architecture of Network

2. Training and Certification

Implement the training and certification to lay the groundwork for promotion and application of innovative method. Rely on Chinese Innovation Method Society to provide certificated training of national innovation engineering and national innovation trainer. Provide internal training of TRIZ to enterprise. Cooperate with Matriz and other foreign Institute, invite the experts of Matriz to offer high level lectures, send visiting scholars to foreign Institute, carry out the international exchange and improve the ability of local team to apply TRIZ0. By the end of 2015, tens of thousands people have participated in the training of innovative method which TRIZ is the main content0, 242 people have gotten the second level certification of national innovation engineering(A total of 1868 people in the country, accounting for 12.96%), 7 people have gotten the third level certification of national innovation engineering(A total of 25 people in the country, accounting for 28%), 10 people have gotten the first level certification of national innovation trainer(A total of 81 people in the country, accounting for 12.35%), 6 people have gotten second level certification of Matriz, 10 people have gotten the third level certification of Matriz.

3. Teaching and Learning in University

At present, most major universities in Guangdong province, such as South China University of technology, South China Normal University, South China Agricultural University, Guangdong University of technology, and some higher vocational colleges have set up courses of TRIZ0.

More and more pupils have applied TRIZ as a powerful innovative tool in their extra-curricular projects. Some teachers of innovation training take part in extra-curricular project as the advisers, help pupils to apply TRIZ in their disciplinary study. It is evidenced that TRIZ has dramatically improved their study. These practices have gotten remarkable results, including series awards of national competitions0 and Red Dot Award0.

4. Expert Team and Teaching Staff

The expert team of innovation method specialize in work of innovative methodology, their works involve in theoretical study, methodology system and tools in engineering field. The team leader is Prof. Cai Wen of Guangdong University of Technology, most members of team are teachers of School of Electromechanical Engineering and Research Institute of Extenics and Innovation Methods of Guangdong University of Technology0.

Teaching staff of Innovation method is mainly composed of teachers from universities. All members have gotten certificate of national innovation engineering and national innovation trainer, some members have gotten the third level certification of Matriz. Teaching staff undertake responsibility of training for enterprises engineer, teaching in universities, advisory of TRIZ application, engineering problem solving, etc.

5. Application in Enterprises

Enterprises are the major force to apply TRIZ. The industry in Guangdong has its unique characteristics. There are relatively completed industrial clusters and mature industrial ecology0. There are numerous number of manufacturing enterprise in core area of Pearl River Delta, meanwhile, there are a large number of private small size technology-based firms at the Pearl River Delta metropolitan area. It is conducive to promotion of TRIZ in a manner of speaking, on the other hand, it is also great challenge to TRIZ. In a word, the precondition is that promoting and applying of TRIZ must solve the practical problems of enterprises.

As shown in Fig.3, in last several years, promotion of TRIZ in Guangdong province could be split into two stages. At stage I, works are focused on demonstration. 46 companies have been picked out as the pilot enterprise to apply TRIZ0, these pilot enterprises are most designated by government or recommended by industry association. In the whole process, dramatic change has taken place in the attitude of managers and engineers, from whatever, to interest, good, useful, due to the achievement is far beyond their expectation.

At the present, the promotion of TRIZ is at stage II. Since the good effect of pilot enterprises, some enterprises have taken initiative to apply TRIZ.

By the end of 2013, the results of applying TRIZ in pilot enterprises are: solving practical problem 352 items, submitting to the processing of patent 369 items(190 invention patents), economic benefits over 360 million yuan, increasing the average efficiency of R&D over 50%00.

Promotion Stage		
	Task	Activities
Stage I	Demonstration (Pilot Enterprise)	Publicity Internal training Certification Engineering Problem solving Patent application
Stage II	Expand (Enterprise)	Popularization Internal training Certification Engineering Problem solving Patent application Service

Fig 3. Promotion Stage of TRIZ

3. Issues and Recommendation

In recent years, significant achievements and difficulties do both exist in the proceeding of TRIZ promotion in Guangdong province. In order to improve the relative work of TRIZ in Guangdong, we have made some recommendation that focus on the following four level.

3.1. Guide and Support of Government

The developed countries have the tradition attaching importance to soft science such as thinking and methodology, in the public finance fund it is a certain proportion of special support to development of science of thinking and methodology. In China, the develop plan of science and technology are less support to these area, so the corresponding support fund is not enough. Actually, underfunded situation has been partly the bottleneck of popularization of innovative methods.

It is necessary to persist in increasing the financial support innovative methods, and establish cooperation between innovative methods and development of science and technology in accordance with the national strategies of innovation. Introduce TRIZ in government project approving of science and technology to evaluate or forecast technological maturity of a new technique or a research.

3.2. Evaluation Method and Incentives

Present evaluation method of scientific and technological achievement and personal ability has played a negative role on guiding the research work of scientific and technical personnel. In China, SCI (Science Citation Index) and its impact index are the common evaluating index. Although SCI is important, but it does not fully reflect the actual situation of academic research and achievements due to the research work of thinking and methodology and relative papers may not be indexed by SCI. Recently, quantitative evaluation has been the standard evaluation method, in most universities and research institutes, the quantity of papers and short-term economic benefits of project are overweight. As a fundamental research work, work of thinking and methodology needs a long period to achieve the result, it is obviously contrary to present guide. That leads to the results that many researchers choose to give up doing research work related to thinking and methodology0.

It is urgent necessary to modify the evaluation method and related incentive system. It should encourage and support science and technology personnel to learn innovative method and applied in their research work. In the evaluation of research project establishing and achievements appraising, the innovative method and its application should be incorporated into the evaluation index system.

3.3. Training and Application

For training and application, there are three issues which are training system, training evaluation and application improvement.

Systematic training is very important for promotion of TRIZ, application of TRIZ is also benefit from it. The training system contains three components, one is the teaching staff and teaching program, one is consulting agencies, another one is teaching base0.

Now the teaching staff mainly consists of teachers in universities, current teaching staff is not match with the growth of training and inquiring of TRIZ, it is necessary to encourage more science and technology personnel to engage in TRIZ promotion work. Second, it is important to develop more internal training personnel of enterprise. Third, introducing the market mechanism in TRIZ training system to increase the competitiveness and motivation, encourage more commercial agency to participate in the training and consulting of TRIZ. Fourth, to build training base. On the base of progress in the past few years, to expand the training base in universities and research institutes so that to support more training and research work of TRIZ, to build the training base in enterprise to promote training and application of TRIZ in enterprise. Meanwhile, design the different level of training program to match with different training requirement of enterprise and social, implement these program by corresponding teaching staff and consulting agency.

Training effect has been and will be crucial for promotion of TRIZ. To sum up the training programs in the past few year, it is shown that there is not an objective and effective evaluation method for training effect0. How to define and understand the training effect , what are the elements of training effect, what factors affect the training effect, from the view points of enterprise and engineer, what are the difference between their ideas to appraise the training effect, etc. Different enterprise, different trainee, different training program, different training content, different training purpose, there are few studies of these issues. It is significant and valuable to make more efforts on these issues in the future.

In the application of TRIZ, it is need to pay more attention on the following issues. To expand application of TRIZ in more industry, to promote more enterprises to apply TRIZ, to enhance the effectiveness of TRIZ to solve problems, to make trial of expanding the fields of TRIZ application from manufacturing to some new fields. Besides upper issues, another critical issue is to upgrade the level of TRIZ application. Most achievement of current application of TRIZ in enterprise concentrated in first and second level of invention. How to enhance to apply TRIZ to solve problems in high level of invention, to judge technological maturity, to forecast the developing direction of product and technology, to offer a valid tool for strategy formulating of enterprise in marketing competition, new product, and new technology. That is a new challenge for our work in promotion and application of TRIZ.

3.4. Training and Application

Research work is the weakness of TRIZ promotion and application in the past few year. The issues are showing as follows: research of tools of TRIZ and their application, research of integrated application with other innovative methods and managerial tools to make TRIZ more powerful in practice, research of collaboration mechanism among government, enterprise, universities, research institute, commercial service agency.

Extenics is a new discipline that was created by Chinese scholars, it is a methodology of the founding team led by Prof. Cai Wen of Guangdong University of Technology started their work forty year ago, the first paper of Extenics was published in 1983. During the forty year, the theory and method of Extenics are gradually developed, combine with its application in various engineering fields, Extension Engineering have developed its particular methods to solve contradictory problem0. The integrated application of TRIZ and Extenics is a worthy research direction.

4. Conclusion

This paper introduces the promotion and practice of TRIZ in Guangdong, mentions the achievements and existing problems. In the past few years, TRIZ has made considerable progress in Guangdong, but opportunities coexist with challenges. More efforts are required to promote the depth and breadth of TRIZ application in Guangdong province, such as to solve the problem of electronic industry and information technology by TRIZ inventive principles and TRIZ tools, this will help application of TRIZ in more field for better result.

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TYPES OF PSYCHOLOGICAL INERTIA

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Abstract

Since a generally accepted definition of Inventive Thinking is missing at present, the author suggests the following hypothesis. Inventive Thinking is a combination of logical form of thinking that is based on perceived rules, algorithms, judgments and deductive inferences with intuitive form of thinking that is based on sub-consciousness, imagination and fantasy. Logical and intuitive thinking are not only mutually complementary aspects of the single process of inventive thinking, but also a merger of both in the course of this process.

Mechanisms of logical thinking have been studied by scientists quite thoroughly, including studies conducted within TRIZ. All main TRIZ tools have been developed on the basis of these mechanisms. At the same time, intuitive thinking and imagination were blamed by TRIZ classics as "thought jumping". Despite the fact that techniques and methods for creative imagination development were worked out within the frames of TRIZ, they were never integrated with logical tools in order to obtain a single innovation-creation process.

Psychological Inertia (PI) is a key concept in the system of Creative Imagination Development (CID). Since PI represents not only a barrier, but also an invaluable ally in the life of any human, one of the main tasks of CID is to learn how to control PI – to turn it on, to turn it off, to adjust it, etc. And one should start from realizing the fact that PI may manifest itself in different appearances. The author has developed a classification of Psychological Inertia types. In his presentation at the TRIZfest, the author will share practical recommendations for controlling of various types of PI that are based on application of logical TRIZ tools.

Keywords: Psychological Inertia (PI), Creative Imagination Development (CID), predisposition.

1. Introduction

1.1. Levels of Imagination

Imagination is the human's ability to form mental images, or the ability to spontaneously generate images within one's own mind without sensory perception of the object/situation [1].

There are three types/levels of imagination:

- Reproductive (memory-based) imagination – ability to imagine an object/situation that a person has seen at some point in the past [2].
- Reconstructive (integration-based) imagination – ability to imagine an object/situation that a person has never seen as a whole, but its parts are familiar to him/her [3].

- Productive (creative) imagination – ability to imagine an object/situation that a person has never seen either as a whole or in parts [4].

1.2. Innovation and Creative Imagination

Innovation is a creative activity that benefits from both analytical (Six Sigma, QFD, TRIZ, etc.) and creative (Creative Imagination) input. TRIZ and Creative Imagination are complimentary. Creative Imagination fills in the blanks where TRIZ tools either are not fully developed or too general. Even professional TRIZ experts may not be effective in problem solving in the absence of non-trivial thinking and creative imagination.

TRIZ, as well as the most of the Creative Imagination Development tools were developed by G.Altshuller and his followers based on the same principle: analysis of large databases. TRIZ is based on the analysis of the library of patents; similarly Creative Imagination Development is based on the analysis of the library of science fiction ideas.

Intuitive thinking as a whole and creative imagination, as its major component, plays three main roles in the invention creation process.

- Imagination enables one to overcome gaps in logics (that are inevitable in the creative process), assisting to switch from a general hint suggested by one or another logical tool to the specific idea of a solution. In this sense, TRIZ does not reject insight or inspiration at all. Logical tools that are available in TRIZ simply lead an inventor to a non-trivial field, give general prompt (or guiding suggestion), so then he/she has to generate specific solution himself/herself. For instance, the “taking out” principle proposes to separate a certain component or property from an object, but what is actual this component or property – that is up to an inventor. Here is another example. Trimming rules suggests several directions for more or less profound changes in the system in question due to elimination of its components, but what the remaining components the functions of eliminated ones should be transferred to is a problem to be solved by an inventor.
- Imagination enables one to overcome a large number of psychological inertia barriers. These barriers not only do not allow an inventor to find a non-trivial solution, but also makes it impossible for him/her to even comprehend what is important in the original situation and what is not.
- And last, but not least, developed imagination enables one not to get scared by non-trivial and unconventional solutions, which are usually rejected by logical thinking as crazy and impractical ones. In particular, solutions derived from other fields of knowledge in which an inventor feels uncomfortable, are usually rejected habitually. As Altshuller used to say, “Imagination to a problem solver is like courage to a soldier” [5].

1.3. Psychological Inertia

Psychological Inertia (PI) is an acquired behavioural or mental pattern that occurs automatically in response to typical situations. PI is useful in almost all situations. However in a pretty rare non-trivial situations PI become a serious barrier for getting an adequate non-trivial solution.

There are totally 16 currently known types of Psychological Inertia [6]. In this paper the author will introduce 6 of them – the ones that innovators most frequently face and the most dangerous ones.

2. Types of Psychological Inertia

2.1. Inertia of Functional Predisposition

Inertia of functional predisposition is the perception of an object as a carrier of particular function. Our consciousness is tightly fixing an object and its regular main function. For instance, a pencil is for writing, a chair is for sitting, etc. When there is a need to find another application or function for an object we simply cannot recognize its latent features. A pencil is sharp and is capable to make holes in thin objects. A chair is heavy and may be used for pressing something.

The TRIZ tools that are effective for overcoming functional predisposition are Function Analysis, Resources Analysis, Feature Transfer, Function-Oriented Search, and Parallel Evolutionary Lines. In Creative Imagination Development there is a specific tool that is aimed at reducing functional predisposition – method of Robinson Crusoe.

2.2. Inertia of Terminological Predisposition

Inertia of terminological predisposition is the perception of an object's name as a carrier of particular property/function. Here is an example – an icebreaker. What is the icebreaker's function? Is it to break ice? But an icebreaker is pushing ice down rather than breaking it. The actual function of icebreaker is to make a passage in the ice for a ship.

Any information is verbalized in some terms. Our consciousness connects each term with some meaning that in time becomes a stereotype. While perceiving information we are reading or hearing a term, and our memory immediately "helps" us to connect it with some specific meaning. Sometimes, it can be difficult to recognize the other different meanings in the familiar term

. The same object or situation could be described with more or less specific terms. There are several levels of terms' specificity (Fig. 1). The less specific the term is, the lower is corresponding barrier of psychological inertia. However, applying absolutely universal terms (like "thing", or "object", or "piece") we may lose some important part of information.

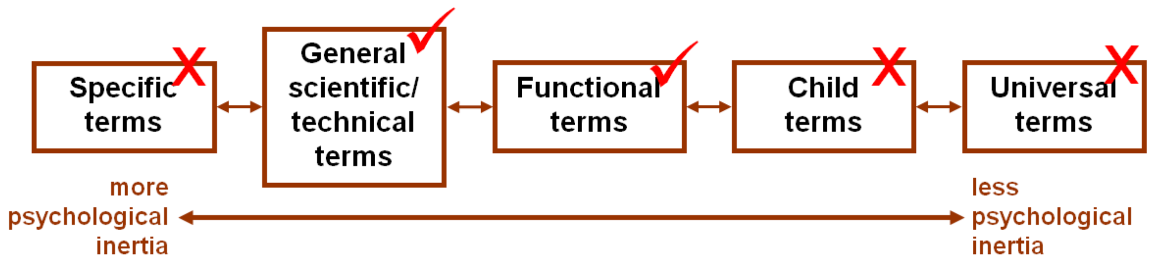

Fig. 1. Terminology chain

Functional terms are the most effective for innovative activities. Transition from a specific term to a functional term may sometimes help you to develop a non-trivial solution. It happens due to making the field of possible analogies much broader.

The TRIZ tools that are effective for overcoming terminological predisposition are Function Analysis, Su-Field Modelling, and Features Audit.

2.3. Inertia of Form Predisposition

Inertia of form or image predisposition is the perception of a typical object's shape and appearance as an immanent property of an object. In our memory a shape is usually associated with object's features and functionality. However the appearance of an object sometimes is misleading, because it doesn't mandatory reflect its operation principle.

It is well-known that some geometrical effects may be a basis of new functions (like Moebius loop or Reuleaux triangle). Changing the shape or geometry of the object may dramatically change its functionality. It may be used for inventive problem solving [7].

The TRIZ tools that are effective for overcoming form or image predisposition are Function Analysis, Features Audit, and Geometrical Effects collection.

2.4. Inertia of Predisposition to Parameters, Features and Characteristics

Inertia of predisposition to parameters, features and characteristics is the perception that objects possess certain properties based on our internal understanding of this object. Objects around us have some features (size, weight, thermal conductivity, etc.), characteristics/states (heavy-light, long-short, hot-cold, etc.) and weight, size, temperature, colour, etc.), and parameters (mass, temperature, thickness, speed, etc.) with some specific value (10 kilograms, 25 degrees Centigrade, 5 meters, etc.). Usually these features and parameters are very familiar to us. That's the basis of this type of Psychological Inertia.

There are three general recommendations for overcoming inertia of predisposition to parameters, features and characteristics:

- We have to check each parameter of an object of innovation. Why this parameter has this specific value?
- Even the parameters that look constant can be changed.
- There are known and latent features and parameters of an object. The latent ones could be a basis for new functions.

The TRIZ tools that are effective for overcoming predisposition to parameters, features and characteristics are Parametric Analysis, Main Parameters of Value Discovery, and Function Modelling.

2.5. Inertia of Non-existent Prohibition

Inertia of non-existent prohibition is the perception of inability to do something because of the wrong internal model (wrong understanding of limitations and constraints). People often build strong limitations (restrictions) and taboos where in fact there are no any limitations (restrictions). These taboos are carriers of a strong psychological inertia. Non-existent prohibition can be:

a). External - "everyone knows that it's impossible". An external prohibition is often perceived as a technical/scientific fact. For instance, Aristotle made a famous mistake when he wrote that a fly has 8 legs. This "fact" was copied over and over into books until medieval times. In the innovation process an external prohibition may come from the client or the boss.

b). Internal - "I know that it's impossible" or "I know how it works". An internal prohibition often related to the authority of some respectful science, company or person.

Sometimes an internal prohibition is a result of wrong modelling/understanding of the real nature of an object or situation. In the innovation process remodelling an object or process allows to overcome the inertia of non-existent prohibition.

One of the tools helping to overcome the inertia of non-existent prohibition is the chain of prohibition transformations (fig. 2). Another tool is analysis of constraints and limitations.

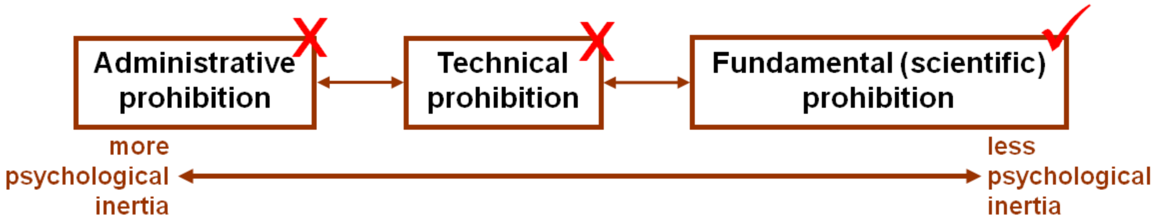

Fig. 2. Chain of prohibition transformations

2.6. Inertia of Predisposition to Action or Sequence of Actions

Inertia of predisposition to action and sequence of actions is the perception that operations/actions have to be performed in a certain way and/or sequence. This type of PI is based on traditional way of doing things and muscle (procedural) memory [8].

The TRIZ tools that are effective for overcoming predisposition to action and sequence of actions are Operation Component Analysis, Flow Analysis, and Function Analysis

2.7. General Recommendations on Reducing of Psychological Inertia Barriers

- Before starting an innovation project make an "audit" of the analyzed object or situation: its current shape, components, features, parameters, sequence of operations, etc.

- For each of the above mentioned characteristics ask functional questions: why they have this particular value?

- Check the analyzed object or situation on presence of all types of PI by applying recommended tools.

- After formulating the solution perform the same actions on the modified object or situation.

3. Conclusions

Mechanisms of logical thinking have been studied by scientists quite thoroughly, including studies conducted within TRIZ. All main TRIZ tools have been developed on the basis of these mechanisms. At the same time, intuitive thinking and imagination were blamed by TRIZ classics as "trials and errors". Despite the fact that techniques and methods for creative imagination development were worked out within the frames of TRIZ (Creative Imagination Development section), they were never integrated with logical tools in order to obtain a single innovation-creation process.

Psychological Inertia is a key concept in the system of Creative Imagination Development. Each object or situation is carriers of some Psychological Inertia. The author has developed a classification of Psychological Inertia types. Usually a particular object or situation represents several types of PI simultaneously. In this paper 6 out of 16 types of PI are presented.

The practical recommendations are also developed on control over different types of PI. These recommendations are based on application of logical TRIZ tools.

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USING THE IDEALIZED DESIGN METHODS TO REALIZE PRODUCT DESIGN

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Abstract

With the development of science and technology, people's life is filled with more and more products. These products can better realize their function, then better serviced for the people. In the fierce competition, there are some problems to be solved. For example, how to make use of design to guide the consumer? How to the meteoric rise in numerous products instead？ How the product designers do the design more efficient?

In this paper, research work mainly revolves around the above problems. First, this paper analyzes the links between the idealized design methods and product design. Innovation is the common aspiration of the idealized design methods and the product design. In such a premise, designers can attempt to apply the idealized design methods into the product design process. It would be a good attempt to achieve product innovation. Secondly, the paper studies the specific conceptual design product, WOOD Hugh - relieve fatigue product suite. In the study of product design, we use the method of improving the level of idealization. This approach can help products achieve a wide range of innovative, such as functional, shape, color, texture, detail, interaction and so on. Finally, based on the above analysis, we can conclude that conclusion. Idealized design approach is an important innovation method of TRIZ. Use idealized design methods in product design is practical and feasible.

In the actual work, there are many product design methods, such as brainstorming. Brainstorming is the most basic approach to product design, however, although this method is very useful but it is not efficient. Therefore, the use of idealized design methods in product design is a good attempt. This will not only be able to expand the designer's vision, but also improve the efficiency of product innovation design.

Keywords: TRIZ; idealized design methods; product design; innovation method

1. Introduction: the idealized design methods and product design

1.1. Innovation is equally important for both

The progress of science and technology, promote product innovation, which together meet the people living in the material and spiritual needs; their relationship is like the egg and egg shell; product design is like a "coat" of technology. It "wrapped" technology. For consumers, product design make the technology be more secure, more stable, and more user-friendly.

Idealized design approach is one of the important theories of TRIZ. At the same time, it is also an important means to help us achieve technological innovation. Designer in product design process, and constantly challenge ourselves to seek innovative. Innovation is the common aspiration of product design and idealized design methodology. Therefore, the use of idealized design in product design method is established.

When designers are building or choosing innovative solutions, they will usually try to increase the idealized level of the system or product. As we all know, the system or product achieve the main function, but also have a negative impact. That is, the product or system obtained useful results, meanwhile produced harmful effects. And such detrimental effect can not be avoided. If you want to improve the idealized level of the system or product design, in simple terms, you need to add useful functionality, while reducing harmful functions. In practice, the ideal conditions do not exist, just as we know, the resistance is not zero, the engine cooling problems and so on. Therefore, in the process of product design, we can learn six ways to improve the level of idealization. And, we should try to use public resources to achieve the necessary functions [1].

1.2. The way to improve the idealized level

While, products achieve the useful effect, it also brings harmful effects. This is the unavoidable fact. Therefore, we should make sure a ratio between the helpful effects of harmful effects, and we should strive to make the useful effect is greater than the harmful effects. For example, social development inevitably affects the natural environment. Although, we make every effort to minimize this effect, but environmental pollution and destruction cannot be avoided. When the designers are doing product design, it is difficult to determine the ratio between the versatility and practicality. In classical TRIZ theory, many outstanding scholars have put forward the method to improve the system ideal level (Figure 1 below). In the following, I will mainly analyze the design process of WOOD Hugh [2]. In the design process, from the creative thinking, design sketches, and other stage of the programs, designers learn to improve system level idealized ideas to solve design problems.

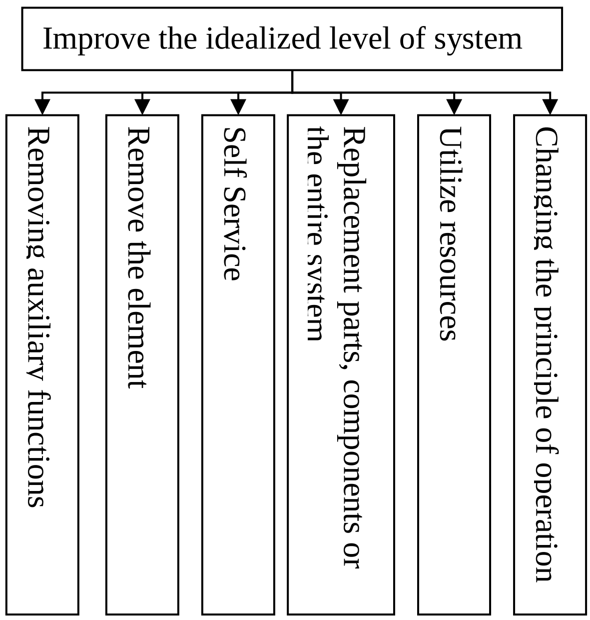

Fig. 1. Methods for improve the ideal level of system

2. Using the idealized idea to realize product design

WOOD Hugh is a suite of products for the user to alleviate fatigue. Modern life is busy and fast-paced. Many people are under tremendous pressure at work and in life. WOOD Hugh response to this situation, it builds a comfortable and relaxing scene. Its scope is broad, whether in the office or at home, users will be able to achieve all-round feel completely relaxed. In many elements of the product design, such as product features, shape, color, texture, detail, interactive and other aspects, designers fully utilize the method of improving the level of idealization. The following will be discussed in detail for various aspects.

2.1. Removing auxiliary functions

Auxiliary function support and help the product to achieve the main function. In many cases, without affecting the main function of the product, you can remove parts or components associated with the auxiliary function [3].

The WOOD Hugh-SPEAKER in Figure 2 is a comfortable playback tools. As we all know, the main feature of the speaker is to play music. Therefore, in the form of design, we followed the "box" shape, and we designed some PA hole arranged uniformly. Allowing users to easily identify the orientation of the sound, easy to put on the desktop, it can also be used for hanging. We designed an appropriate edge chamfer surface, making the speaker feel more comfortable. Unique wood grain texture provides the user with physical and mental pleasure. According to “Removing auxiliary functions", we removed the switch, volume control and other control buttons. After removing these auxiliary functions, the user can manipulate the speaker by APP. As a result, the main features of the player is more prominent, thus achieving a less is more design.

Fig. 2. The WOOD Hugh-SPEAKER

2.2. Remove the element

Often, designers will reserve a large storage space in the lower part of the vase. Because, after the flower vase filled with water, vases can still maintain a stable centre of gravity. Thus, in the form of design, it is difficult to get rid of the vase shape. In WOOD Hugh-VASE (Figure 3 below) design, we removed the "large number of water containers," "long-term gardening" these two functions, we adopted the "small water" and "single gardening" approach. Thus eliminating the traditional "vase shape" and "glass" of these two elements. WOOD Hugh-VASE using the pine as the design material, it is compact, suitable for desktop decoration. But it is also a decoration, it can be carried and make user feel comfortable.

Fig. 3. The WOOD Hugh-VASE

2.3. Self Service

In order to simultaneously complete the auxiliary functions, we may sacrifice some of the main features. We use the method to implement auxiliary functions， which we have used to achieve the main functions [4]. In many cases, if there is no auxiliary component, the system will become more efficient. WOOD Hugh-LED (Figure 4 below) is an example of such a self-service.

We have designed the WOOD Hugh-LED interior sufficient space, so, you can grow spider plants in it. Its lighting layout suitable for the desktop, it can be used for decoration, and it can also be used for hanging. When hanging, you can plant small spider plants in it. Although, this design will weaken part of the illumination function, because the Chlorophytum leaves would obscure part of the light. Precisely because of this, the mottled and soft light, make people feel comfortable and relaxed. At the same time, in this way, it is possible to remove part of the components connected with auxiliary functions, such as traditional lampshades. Therefore, comparatively speaking, this design allows WOOD Hugh-LED become more practical and effective to use.

Fig. 4. The WOOD Hugh-LED

2.4. Replacement parts, components or the entire system

WOOD Hugh- INCENSE (Figure 5 below) consists of two identical parts. You should merge two boards to work properly. It is applicable to the desktop for decoration. It is used basic wood material, easy for customer to carry. In the design, we have replaced the traditional expensive ceramic material with low-cost components. Meanwhile, the same modular components are easy to storage; they do not take up extra desktop space.

Fig. 5. The WOOD Hugh- INCENSE

2.5. Utilize resources

There are many kinds of resources, including materials, energy and other products present in the environment properties. Direct resource is the resource that can be quickly utilized. Derived resource is the resource can be utilized after conversion. In product design, it is possible to achieve a certain function through the use of resources, thus simplifying the system components. WOOD Hugh- HUMIDIFIER, as shown in Fig. 6, is a humidifier with a bonsai. It is applicable to the desktop for decoration. Its shape is simple and elegant; you are free to choose the type of pot in it. In the design, we make full use of system resources to achieve "humidification" function. We put the "aromatherapy" and "humidification" together to achieve the two functions in the same product.

Fig. 6. The WOOD Hugh- INCENSE

2.6. Changing the principle of operation

In order to simplify the system or operation process, we consider changing the basic operating. WOOD Hugh, as shown in Fig. 7, is a simple suit of product. It contains methods of multiple dimensions to relieve fatigue. We fully considered whether the product is easy to carry. This is a very difficult design. We use the form of the product family. We dispersed the product components. Therefore, it is necessary to design the structure of each component, but also it is necessary to study the overall shape of the product. In market research, we found that pain point of the design is that the users can not extract the entire time for rest. Therefore, in this design, we distributed the relieve fatigue treatment to each component. Affect users in the subtle, soothing fatigue unconsciously. Completely change the mode of the previous product. Through product design, we improved ways to relieve fatigue. At the same time, this package can be composed of gift boxes, direct-to-market.

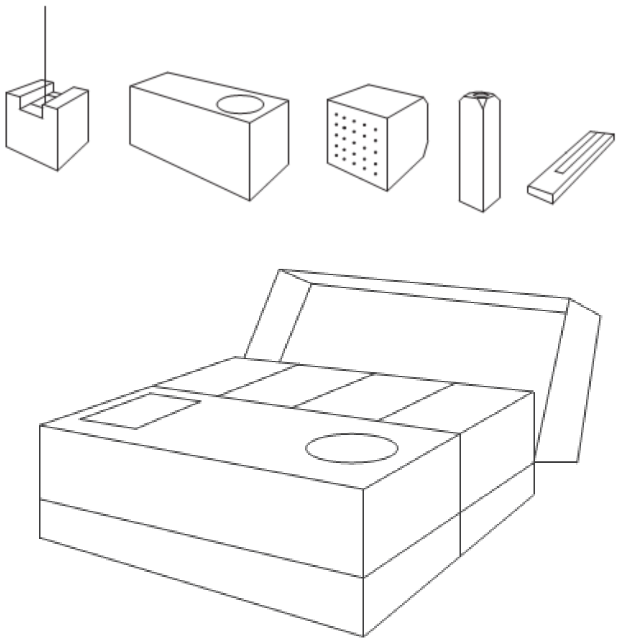

Fig. 7. The WOOD Hugh

3. Conclusions

According to the analysis above, we can draw the following conclusions:

First, we can use method to improve the level of idealized in product design. WOOD Hugh proved that, this design approach used in product design is feasible. TRIZ and idealized thinking method are both effective means to achieve innovative design. At the same time, innovative is final demand for product design.

Second, the application of the idealized design approach can improve the efficiency of product design. There are many design methods we can use in the product design process. The idealized design approach is targeted; it can improve the efficiency of designers. When we designing WOOD Hugh, this targeted solutions achieved a multiplier effect.

Thirdly, the applicability of this approach needs to be verified. The method is applicable to WOOD Hugh. In other words, this method is suitable for such small product. But its broad applicability remains to be verified. This can be explored in a future study.

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