ISSN: 2374-2275
ISBN: 978-0-692-52417-6

Organized by the International TRIZ Association – MATRIZ

THE 11TH INTERNATIONAL CONFERENCE

TRIZ*fest*-2015

THEORIES AND APPLICATIONS

CONFERENCE PROCEEDINGS

September 10-12, 2015, Seoul, South Korea

Editors: Valeri Souchkov, Tuomo Kässi

Supported by

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INNOBIZ 기술혁신형중소기업

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Proceedings of the 11th TRIZ*fest*-2015 International Conference
September 10-12, 2015. Seoul, South Korea
Organized by the International TRIZ Association – MATRIZ
Supported by: INNOBIZ, Research & Business Development Partners, Small and Medium Business Administration.
Seoul, South Korea, 2015. – 322 pages.
ISSN: 2374-2275
ISBN: 978-0-692-52417-6

Editors:

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The collection of papers «Proceedings of the 11th TRIZfest 2015 International Conference» is intended for TRIZ specialists and users, 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 peer-reviewed.

Series "*Proceedings of the TRIZfest International Conference*", ISSN: 2374-2275

Published and printed by the International TRIZ Association – MATRIZ, 8946 Wesley Place, Knoxville, TN 37922 USA

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Dear Friends!

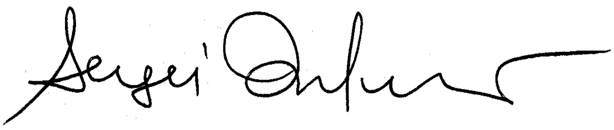
It is my honor and privilege to welcome you to the 11th MATRIZ annual conference of 2015 in Seoul. The geography of MATRIZ conferences has expanded from Saint Petersburg and Moscow in Russia to Lappeenranta in Finland, Kiev in Ukraine, Prague in the Czech Republic and now Soul, South Korea.

The choice for Seoul was natural. This country has been pioneering TRIZ deployment for many years , making TRIZ a part of the engineering cultures at Samsung, Hyundai Motor, LG, POSCO and many other world leading corporations of South Korea.

TRIZfest of 2015 is focusing on the theories and applications of innovation methods and, of course TRIZ being one of the most efficient approaches , is a centerpiece of it. We are happy to host both experts in academia and education as well as talented engineers from the most creative companies in the world – Samsung, General Electric, Hyundai Motor Group, Continental Automotive and many others.

I am sure that the diverse and extensive experience of the conference participants, vast geography – we have presenters from Europe, Asia and Americas, passion and dedication of the participants to innovation and TRIZ will make the conference creative, enjoyable and fun.

I wish you all productive discussions, useful networking, exciting findings and to have a wonderful time in Seoul!



Sincerely,
Sergei Ikovenko,
President of the International TRIZ Association
(MATRIZ)

Dear All,

We would like to send out our sincerest welcome to all of you to the 11th International TRIZ Conference, TRIZfest-2015. Helping to prepare for this year's conference has been a great honor and an immensely exciting experience for us as it is the first time TRIZfest has been held in Asia.

2015 also marks the twentieth anniversary that TRIZ has been introduced to Korea. It has been all the more meaningful as TRIZ has been gaining stronger, wider ground in Korea in the past twenty years since TRIZ was first introduced in Korea.

Today, the significance of TRIZ in innovation has gained recognition from major companies in Korea in which it was implemented, but also by government agencies. These agencies are funding nationwide programs to spread TRIZ education and implementation for small- and medium-sized enterprises.

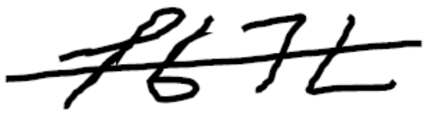
It is an undeniable fact that creative product and technology development is now an inseparable element of problem solving. TRIZ is making this possible for an increasingly wider range of people.

Everyone attending this conference is a contributor to the development of TRIZ, and hence,

improvement of the solutions to the countless number of problems that we have.

We hope that you will take back with you worthwhile content and many good memories with fellow people from our TRIZ community.

With Warmest Regards,



Yongpyo Lee

CEO

R&BD Partners

Seoul, South Korea

Dear TRIZfest 2015 participants,

Welcome to Seoul! It is a pleasure to announce the proceedings of the 11th International Conference "TRIZfest 2015" which will be conducted on September 10-12 in Seoul, South Korea.

It is very important to note that this year the conference is conducted in South Korea which undoubtedly has become a leading country in the world to use TRIZ and Systematic Innovation. Top multination Korean companies such as Hyndai, LG, POSCO, Samsung and others have been effectively using TRIZ to innovate their products and services on a large scale and their experience is extremely valuable to recognize potential for future development of methods and tools of TRIZ.

The conference focuses on the following main topics:

- TRIZ research
- Development of new methods and tools related to TRIZ
- Intergration 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 believe that all the authors who presented their works in these proceedings provided considerable contribution to the development of TRIZ and its dissemination around the world.

We would like to express our sincere gratitude to every author and co-author who contributed to TRIZfest 2015 and all the members of the TRIZfest Organizing Committee who provided their help and support to the Paper Review Committee during preparation of the conference.

Valeri Souchkov, TRIZ Master
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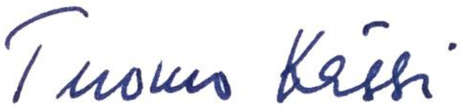

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TRIZ*fest* 2015

A NEW ANALYSIS MODEL – SAFC MODEL

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Abstract

This paper constructs a new analysis model called SAFC model by combining the Su-field, Attribute, Function and Causality analysis together. By several case studies, it concludes that SAFC model could facilitate people to find the attributes of substances or components with harmful function in technical system exactly, and find the effective way to deal with those unnecessary attributes by effective operation, which enhance the efficiency of learning and using TRIZ.

Key words ：SAFC, Analysis, Model, Substance, Attribute, Function, Causal, Interaction

1. The basic structure of SAFC model

SAFC model is a composite analysis models, based on the Su-Field model, while incorporating the Attribute analysis, Functional analysis and Causal analysis models. Take the acronym of these four analysis models, named it “SAFC” model.

It is an important, comprehensive tool in U-TRIZ (developed by authors, omit the introduction), that unified the tools of problems analysis and solving. The meaningful characteristics of this model can be used to analyze and solve problems with one model, in one process, at the same time.

Some symbols will be used in a SAFC model: substance S_1, S_2, S_3; attribute A_1, A_2, A_3; useful function F_{u1}, F_{u2}, F_{u3}; harmful function F_{h1}, F_{h2}, F_{h3}; mixed function F_{uh}.

Any problems within a technical system are related with substances and its attributes. All the harmful functions are formed by the interaction of attributes of substances. The invention task must be focus on function, the attribute of the substances of the key elements, and their interactions.

Attribute definition: the attribute is the essential characteristics of a substance that obviously distinguished to other substances. Attribute is the basic concepts and essential elements to define functions, because the attributes directly related to the function. Using attributes skillfully, we can build up or manipulate functions in any technical system. Broadly speaking, all attributes of substances are the resource to solve the inventive problems.

Function definition: the function is the interaction of two attributes of two substances, to change or maintain one of the attribute of two substances, or influences, stimulates an attribute of third substance. Substance and function are linked by attributes.

Function also has its own attributes. The customer willing to buy a product, actually they are purchasing the product function. Deeper understanding, in fact, they are actually purchasing the attributes of product function. The customer's description and feel for a product, the product functions they described are often the attributes of product function. For example, customers often say, a knife should be sharp so that it doesn't need sharpening after many years use, cooked rice with a rice cooker should be delicious, the washing machine should have the sun exposure flavor, etc. Here, the customer requirements "sharp", "delicious", "sun exposure flavor" etc., are the attributes of product function.

If we show a function with a graph, we draw a "box + lines" (interaction of attributes of substances); if we show a function with semantics, we use "VO" format (verb+ object) to describe it, like the "*add water*" or "*hit tree*".

To heritage the Su-Field model, but with more elements -- in a SAFC model, S_1 and S_2 are two substances, they have attributes A_1 and A_2. Generally, substance S_1 is the function carrier (the subject issued a action), substance S_2 is the object (the object received the action); F_{uh} is formed by the interaction of attribute A_1 of substance S_1 and attribute A_2 of substance S_2, it may be a useful function or a harmful function; S3 is the third substance with attributes A_3, derived after achieving the function F_{uh}; both A_1 and A_2 are not only formed a function, but also both formed a causal result of S_3 (Fig.1).

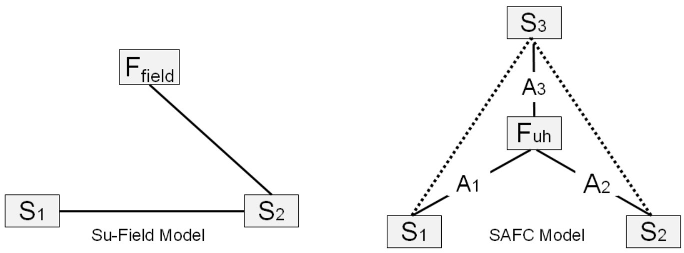

Fig.1. A Su-Field model compare with a SAFC model

If we compare the Su-Field model and SAFC model, we can find differences:

1) SAFC offered the 3rd substance (result) S_3 that derived by two substances' interaction in one model;

2) SAFC directly given the function F_{uh}, but in a Su-Field model, we don't know where is the "function";

3) SAFC demonstrated causal result directly, S_1 and S_2 are causes, S_3 is the result. Su-Field models don't offer such information.

According above points, we think that SAFC model contains more information, would have more advantages in the problem analysis and solving process.

2. SAFC model was build up based on the axiom

Axiom: The interaction between substances is an axiom.

Based on interaction axiom, we use the following four inferences to represent the process of building up the SAFC model and the internal logics.

Inference I: function is a result of interaction of two attributes (A_1, A_2) of substances (S_1, S_2), formed a functions F_{uh}.

For example, driving a car S_1 accidentally hit a tree S_2. Moving car has the "movement" attribute, and the stationary tree has the "blocking" attribute, "*hit tree*" is a function that formed by "movement" and "blocking", and attribute of the tree / car was changed. From the viewpoint of bi-direction interaction, it can be considered a car "*hit tree*", it also can be considered a tree "*hit car*" (Fig.2).

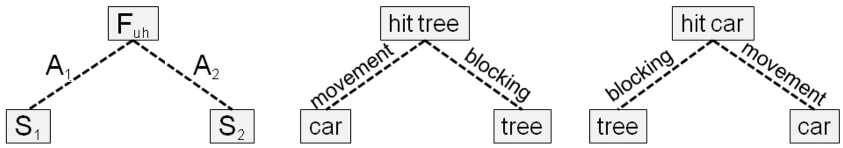

Fig.2. Inference I and example

Inference II: The function's attribute of F_{uh} that formed by interaction of two attributes (A_1, A_2) of two substances (S_1, S_2), equals to the attribute A_3 of third substance S_3, they were docking each other.

For example, driving a car S_1 hit the tree S_2, the derived substance of S_3 may be "bent bumper" and / or "crashed bark". According to the key issues in the problem, after the function Fuh formed, we can determine which one (car S_1 or tree S_2) would be the 3rd derived substance and its attribute. Here, both "crashed bark" and "bent bumper" have the common attribute A_3 -- "deformability" (Fig.3).

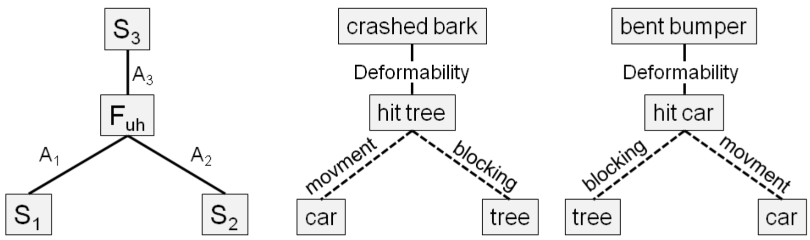

Fig.3. Inference II and example

Inference III: Causal result S_3 is an interaction of two attributes (A_1, A_2) of substances (S_1, S_2), the base level is the causal substances (S_1, S_2), the top level is the result's substance S_3.

For example, the causal substance "moving car" hits "stationary tree", its causal result S_3 is "bent bumper" and/or "crashed bark" (Fig.4).

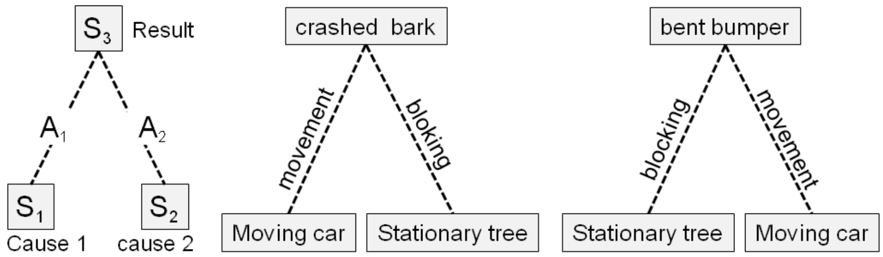

Fig.4. Inference III and example

Inference IV: Functions result and causal result are both the result of interaction of attributes (A_1, A_2) of substances (S_1, S_2), Functions results and causal results are directly related via the attribute A_3.

The functional result formed in Inference II, and causal result formed in inference IV, they are correlation and complementary each other. The interaction of attributes (A_1, A_2) of substances (S_1, S_2), not only formed the functional results F_{uh}, but also formed the causal result S_3. And, the functional result F_{uh} is connect the causal result S_3 via attribute A_3, A_3 is both the attribute of function F_{uh}, also is the attribute of derived substance S_3. Finally, we get a composite triangle SAFC model with the inference II plus inference IV (Fig.5).

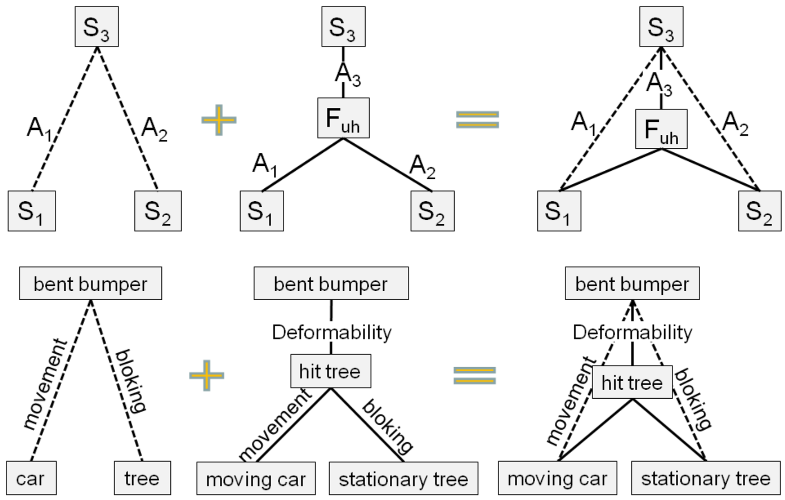

Fig.5. Inference IV and example

In Fig.5, for example, moving car S_1 has the "movement" attribute, and the stationary tree S_2 has the "blocking" attribute, they are interacted, formed a harmful functions "*hit tree*". The function attribute "deformability" will lead to that original S_3 (bumper) become a "bent bumper" with a "deformability" attribute A_3.

3. SAFC model's constituent elements

SAFC model has the following parts and meanings:

1) The basic shape: SAFC model is a triangle model with three levels. Each triangle model clearly represents a function and a layer of causality.

2) Constituent elements: S_1, S_2, S_3 are the substances, A_1, A_2, A_3 are the substance attributes. Usually, we use the solid lines or dashed lines to connect a substance to another substance, or a substance to a function, the lines means the attribute transfer;

3) Interaction's result: the two solid lines interaction means a function result F_{uh} that formed by two attributes of two substances (useful functions or harmful functions), the two dashed lines (S_1 to S_3, S_2 to S_3) interaction means a causal result that formed by two attributes of two substances;

4) Interaction's direction: in the direction of the causal interaction, dashed line from bottom to top, is indicated by the direction from causes to result; from top to bottom, is represented by the direction from result to the causes. In the direction of Function connected with the solid lines, substance S_1 is the function carrier (Subject), the main action is issued by S_1, the substance S_2 is a functional receptor (Object), accepted the action. The function format is "VO". Of course, due to the interaction is bi-direction between the S_1 and S_2, so the main action may be issued from S_1 applied to S_2, or from S_2 to S_1;

4) Interaction's timing: SAFC model represents each round of interaction at the micro area. Therefore, the actual development order of interaction is from the bottom to top. There will have the interaction firstly, will have the interaction result (function) secondly. Therefore S_1 and S_2 must be placed in the bottom of the triangle, S_3 is the final result, placed on the top of the triangle, F_{uh} must be at the center of the triangle, beneath the S_3 and A_3 located, indicating the causality and timing relationship.

5) Results' status: S_3 is a derived substance with the attribute A_3, it comes from the existing deformed S_1 or S_2, or a part of the S_1 or S_2 (e.g. bent bumper, barbecue drop out oil), or is superimposed substance "$S_1 + S_2$" (e.g. bimetal, wood with screws), or fusion substance s "$S_1 \times S_2$" (e.g. alloys, compounds). See (Fig.6).

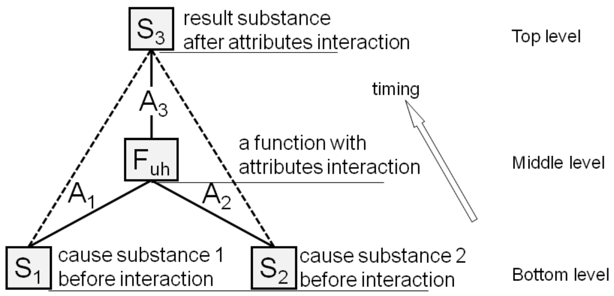

Fig.6. SAFC model's shape, timing and results' status

Sometimes then things will become a little bit complex: after the interaction of (S_1, S_2), generated a desired useful function and a wanted S_3, but also generated some unwanted derived functions (like harmful function) and some unwanted derived S_3.

For example: A barbecue problem analysis (charcoal fire to heat raw meat), charcoal fire is S_1, has the "Heat convective" attribute, raw meat is S_2, has the "heatable", "heat- shrinkable", "inflammability" attributes. The interaction of two attributes of (S_1, S_2) formed a useful function "*heat meat*", and accompanied with derived functions "*shrink meat*", "*squeeze out oil*" and "*burn meat*". If the charcoal fire heating continued, the state of the raw meat will be continuously changed, generated a continuously changed S_3, if we omitted the most intermediate states but only to consider some key status, then the state of S_3 may start from "raw meat" changed to→ "half-cooked meat (with oil)" →"squeezed meat (with oil)" → "cooked (with oil)" → "burned meat (with oil), etc., and that "squeezed oil" may drip into the burning charcoal to cause "*burn oil*" and "*generate smoke*" functions, also the oil further changing into a secondary derived substance "smoke". According to the context of this issue, our concern only one results S_3 -- it is "cooked meat", all the others results derived from substance S2, like "squeezed oil", "burned meat" and "smoke", are unwanted results. Therefore, from a functional viewpoint, it is clear that "*burn meat*" is harmful function, and although the "*squeeze out oil*" is a neutral function, but the oil drop into the burned charcoal fire, caused the "*burn oil*" and "*generate smoke*" harmful functions. See SAFC analysis about charcoal fire barbecue (Fig.7).

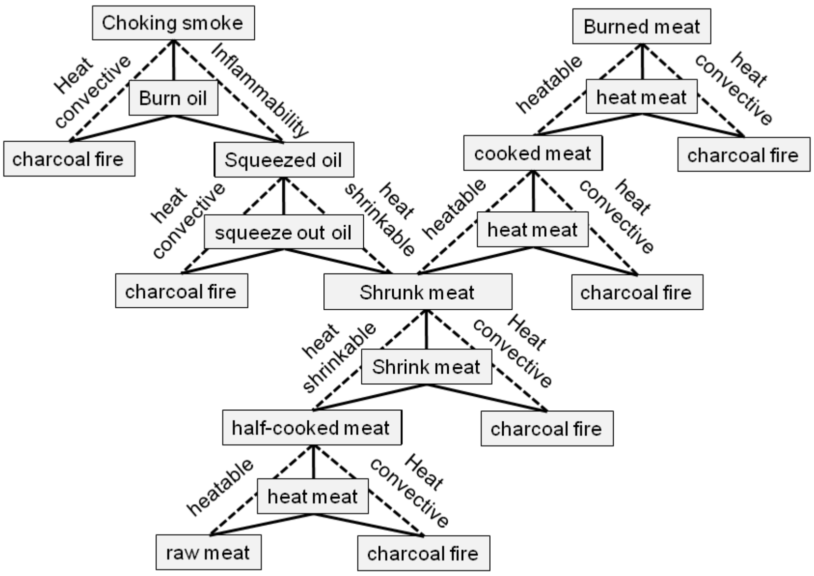

Fig.7. The SAFC analysis about charcoal fire barbecue

Although the analysis process is slightly more complicated, but if we analyze the timing carefully, to process the attributes of substance interaction one by one, we will be able to define the right timing and interactions, to get the correct S_3 with right status.

4. Use SAFC model to analyze contradiction

Basically, contradiction formed according to the attributes of substances. Usually, we think that contradiction can be formed by the unity of opposites of two parameters (technical contradiction, TC), it may be formed by the unity of opposites of two demands (physical contradiction, PC). But in fact, behind the parameters and requirements, attributes of substances are the decisive, essential roles.

We can put TC and PC in a unified composite model SAFC (Fig.8).

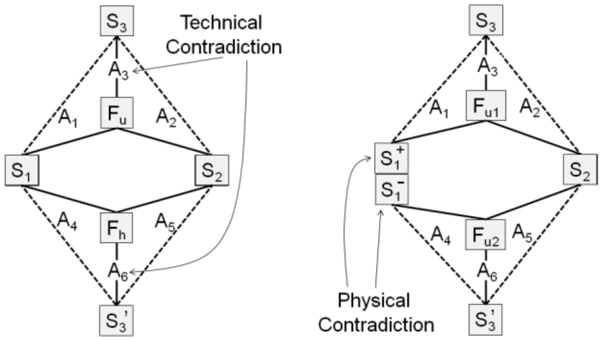

Fig. 8. Represents TC and PC in a SAFC model

TC is placed on the left in Fig.9. The substance S_1 and S_2 two interacting with a variety of attributes (A_1, A_2, A_4, A_5, etc.), so in the event of interaction, generate a useful function F_u, also produces a harmful function F_h, two functional attributes A_3 and A_6 are mutually contradictory, improving the A_3 deteriorates the A_6, and vice versa. This is a typical TC (A_3 vs. A_6).

PC is placed on the right in Fig.9. S_1 and S_2 after interaction produced two useful functions F_{u1} and F_{u2}, if we ask both useful functions, it means we applied total different demands to S_1 (also can be S_2).

For example, armored tank’s fighting capacities are reflected in function attributes both of the offensive and defensive capacities. Thus, the tank is necessary to have a attribute “mobility”, but also to have an attribute “protection”. Thick armor can improve the tank’s attribute “protection”, but will increase the weight, deteriorates tank’s attribute “mobility”.

In this example, thick armor will bring a useful function "*stop shells*" (which attribute is "protection"), but will bring a harmful functions "*aggravated body*" (which attribute is "mobility"), so one of the tank’s TC is "protection vs. mobility".

When we ask to achieve two useful functions "*stop shells*" and "*reducing weight*", then you will find the PC focus on "armor thickness", there are two totally different needs on this parameter: thick (to meet the "protection") , thin (to meet the "mobility"). (Fig.9).

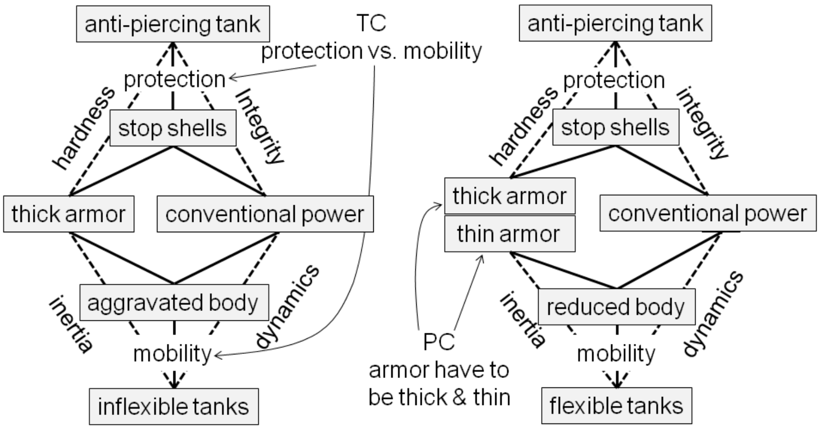

Fig.9. TC and PC represented in a tank's SAFC model

5. Use SAFC model to solve problems

SAFC model not only be used to analyze problems, but also to solve the problems. There are six applying modes in the problem-solving situation based on SAFC model: Replacement mode, Superposition mode, Parallel mode, Series mode, Composite mode, Inner-adjust mode. Limited to the length of the article, we only introduce the Inner-adjust mode.

Direct manipulate the substance attribute of the components in an existing system can improve an existing system. New attributes ($S_{2'}$ etc.) could come from internal unrecognized attribute or has not been utilized attribute of existing substance S_1 and / or S_2, could not be obtained from the external substance (Fig.10).

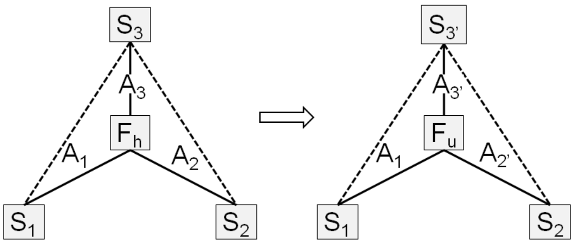

Fig.10. Inner-adjust mode

Examples: Flanges seal docking. Classic seal structure is joint two flanges together with seal ring, multiple bolts tighten flanges. Seal strength depends on the bolt numbers around flange edge and bolt tightening degree. Pressure P between the flanges' face is equivalent to the bolt pressure. Multiple bolts increase the complexity of the structure. It seems impossible if we want to reduce the bolt numbers while increasing the pressure P between the flanges' end face (increase seal strength). However, if we change a flange's end face from the plane perpendicular to the axis, into a small angle θ slightly tapered surface (new attribute), once we tighten the bolts to press flange face, let θ tends to zero (slight deformation), it can exponentially enlarge pressure P (bring another new attribute), then we can get an ideal result: both to reduce the bolt number, while increasing seal strength (Fig.11).

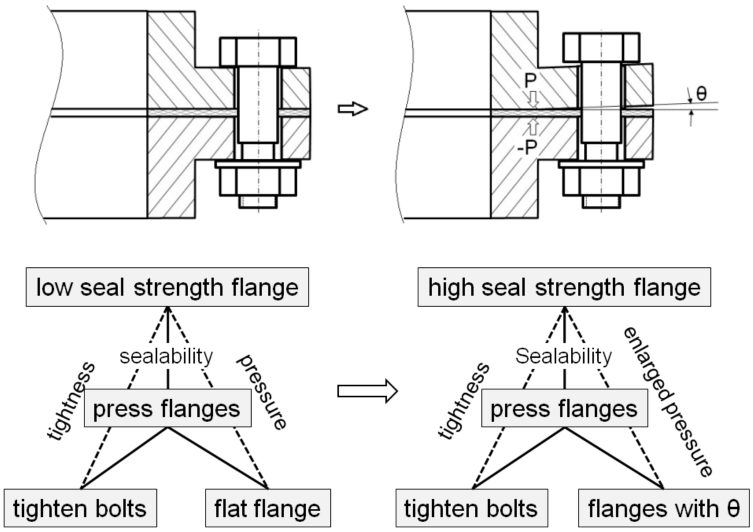

Fig.11. To increase seal strength of flanges

6. Conclusions

SAFC model is one of new model in TRIZ tools. It unified the problems analysis and solving process, so we can use it to analyze and solve the problems with one model, in one process, at the same time.

SAFC model was constructed based on Su-field model, it can substitute many situations to use the Su-field model. Also, it can do the function analysis, attribute analysis simultaneously.

SAFC model could facilitate people to find the attributes of substances or components with harmful function in technical system exactly, and find the effective way to deal with those unnecessary attributes by effective operation, which enhance the efficiency of learning and using TRIZ.

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TRIZ*fest* 2015

A PRODUCT PLANNING APPROACH BY TRIZ AND IIM

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Abstract

The theory of inventive problem solving (TRIZ) is among the most effective solutions for new product planning, and in our previous studies, we have proposed some approaches using TRIZ to improve products. Sawaguchi proposed effective new product planning activities utilizing "the patterns of technological system evolution." However, we found that there were many cases in which certain features might be degraded even if some new functions had been created by these approaches. In practical product planning, new integrated evaluation methods comparing current products against those with new functions are required. Although the information integration method (IIM) is a quantitative evaluation method for products, new functions cannot be evaluated using this method. In this study, we propose a new quantitative product planning approach based on the IIM by assuming that there is potential demand for a new function even if current products do not have the function. We applied this product planning approach to hair dryer improvement planning as a case study.

Keywords: ThePatterns of Technological System Evolution, Product Planning, Information Integration Method

Motivation

Sawaguchi found the possibility of effective new product planning activities utilizing "the patterns of technological system evolution" of the theory of inventive problem solving (TRIZ) [1]. We also proposed some approaches using TRIZ, such as "an effective cost reduction method based on TRIZ" [2]. In that study, we applied TRIZ to not only cost reduction processes but also product development processes. In addition, we proposed "problem solving processes based on expert engineers' way of thinking" [3]. We clarified the differences in the problem solving processes between expert and non-expert engineers and developed an effective problem solving process based on TRIZ, so that non-expert engineers could solve problems in the same manner as expert engineers.

However, we found there were many cases in which certain features might be degraded even if some new functions had been created by these approaches. In actual product planning, product functions created by these approaches are evaluated by subjective opinion, because a quantitative evaluation method for product planning has not been established [4]. The information integration method (IIM) is a quantitative evaluation method for the improvement of products [5]. We have already proposed a product improvement process using the IIM and TRIZ [6]. However, it is difficult to evaluate new functions that do not exist in current products using the IIM because this method is assumed to compare the features of existing functions. In this study, we propose a new quantitative product planning approach based on the IIM by assuming that there will be potential demand for new functions even in current products (Fig. 1).

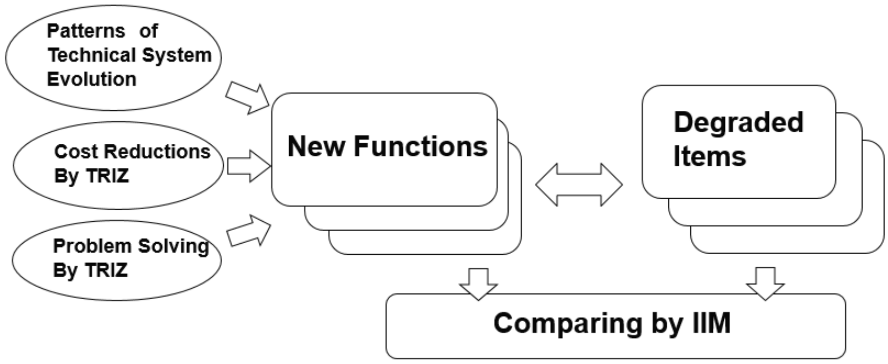


Fig. 1 Relationship between TRIZ and IIM.

1. Information Integration Method

The IIM helps evaluate requested features for system optimization. In this method, all features are evaluated using a common measure called Information on the basis of Shannon's information theory. Information is defined by the following mathematical formulas [7].

Information I for communicating the status of feature a, which is associated with probability P_a, is given as follows.

$$I = \ln \frac{1}{P_a} \qquad (1)$$

Suh declared this concept an axiom [8]. It is defined that Information I is described in formula (1) by P_a, the probability of satisfying feature a, and that a smaller I makes it easier to satisfy feature a.

In the IIM, the system range is defined as the range of a feature in a product (or system); the design range is defined as the range of a feature requested from markets or customers; and the common range is obtained when the system and design ranges overlap (Fig. 2) [8].

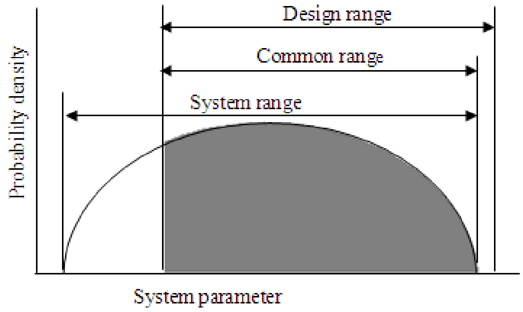


Fig. 2 Probability distribution of system parameters (1).

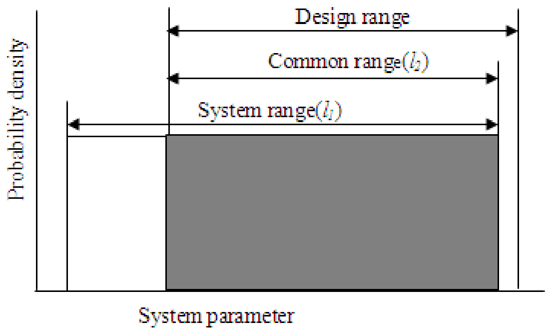


Fig. 3 Probability distribution of system parameters (2).

A higher design range probability density is indicative of a higher level of satisfaction with the requested product feature. In the IIM, to obtain the common range in probability P_c, I is used as a measure for evaluating the design. It is assumed that the probability density of most product features can be approximated for a uniform distribution. I can be defined as follows if the probability density is subject to continuous uniform distribution (Fig. 3) [8].

$$I = \ln \frac{1}{P_c} = \ln \frac{SystemRange(l_1)}{CommonRange(l_2)} \qquad (2)$$

Using the IIM, Information can be infinite when it is out of the design range. Even if other features are satisfied by requested features, the design will not be selected if one of the features falls outside the design range. To address such situations, a common range coefficient k is proposed in the IIM. As shown in Fig. 4, the design range falls between feature parameters a and b, although the feature parameter that should be satisfied is c. In this case, $k = 1$, where the system feature parameter is between a and b. $k = 0$ when the system range parameter is between 0 and c. k is described in equation 3 (below) where the system range parameter is between a and c, assuming there is a small system range of width w (Fig. 4).

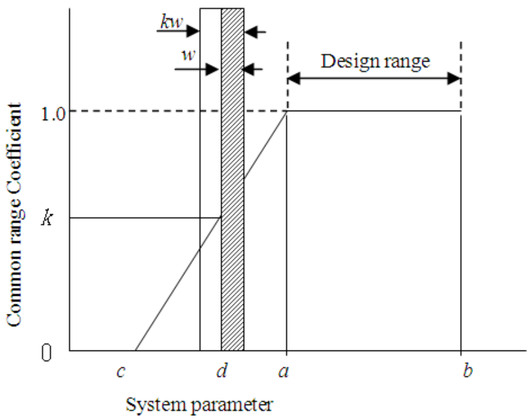


Fig. 4 Common range coefficient.

$$I = \ln \frac{w}{kw} = \ln \frac{1}{k} \quad (3)$$

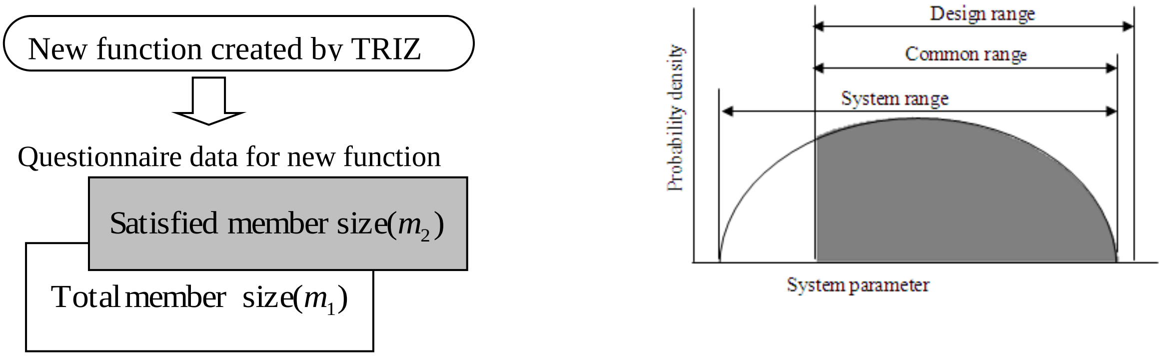
Total Information I_T is the amount of feature Information, I_i is the Information of feature i, and n is the number of features. In this study, I_T was used as a common evaluation measure of the improved design. The IIM was used with the Nakazawa method in combination with the experimental design [9]:

$$I_T = \sum I_i \ \ (i = 1 \ldots n) \quad (4)$$

2. Product Planning based on IIM

Although the IIM can be applied to the evaluation of products, it is difficult to compare current products against those with new functions using this method. This is because a new function that does not exist in current products cannot be evaluated. There is no common range in current products for new functions. But in many cases, current products are selected by customers if other features (such as cost) are much better than those with new functions.

We have emphasized that P_c is the probability of satisfying a request for products in the IIM. We propose the substitution of potential requests for new functions instead of satisfaction level in the IIM and calculate potential requests from questionnaire data for a new function. This means that P_c can be calculated from questionnaire data for new functions in current products (Fig. 5). By this method, I can be obtained from the following formula:



$$I = \ln \frac{1}{P_c} = \ln \frac{\text{Total member size}(m_1)}{\text{Satisfied member size}(m_2)} \qquad \textbf{(5)}$$

We propose a quantitative product planning approach by comparing current products against those with new functions in I_T using the TRIZ and IIM (Fig. 6).

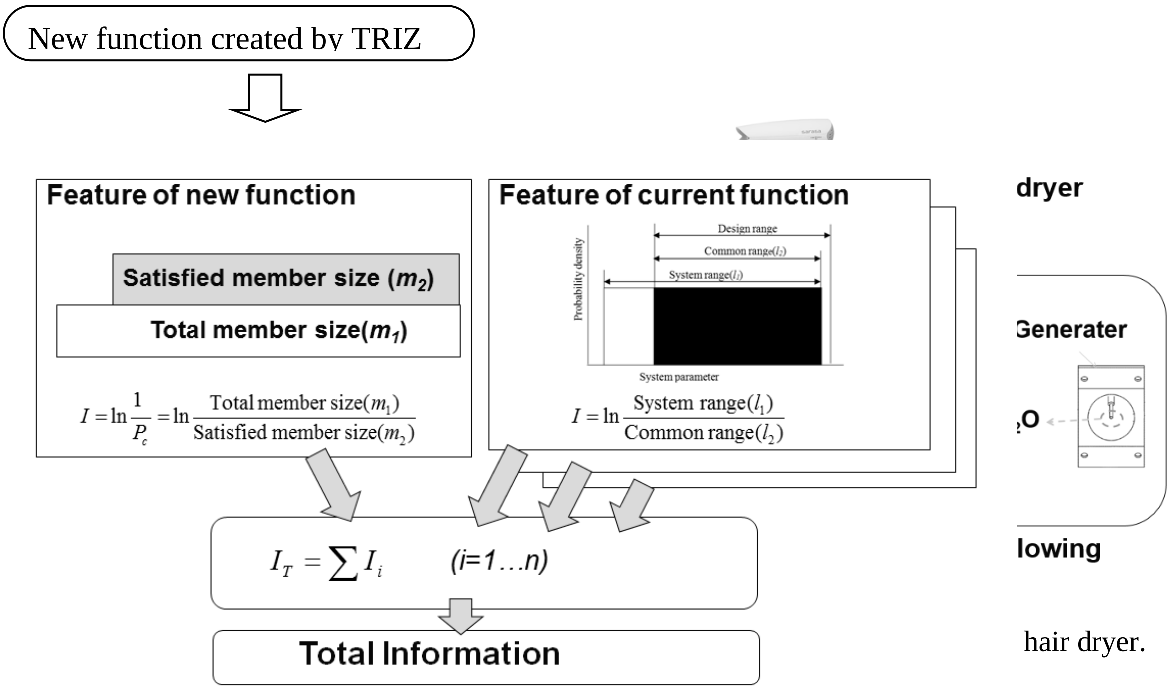


Fig. 6. Product planning approach using TRIZ and IIM.

3. Case study

4.1. Target of case study

We applied this approach to hair dryer improvement planning as a case study. Although drying by blowing warm air is the main function in current hair dryers, the blowing of ionized air has been requested for its effect of making the hair more lustrous. This was based on effective new product planning activities that utilize “the patterns of technological system evolution.” However, ionized air easily disperses in the surrounding dry air. To solve this issue, we focused on TRIZ principle No. 13 [10] “The Other Way Around,” which prompted us to think in reverse. The blowing of wet ionized air is proposed as a new function for lustrous hair, although drying is the main function of a hair dryer. While ionized air can contribute to lustrous hair, it requires a dryer that is more costly and heavier than current ones (Fig. 7). In this product planning exercise, we compared current and ionized air hair dryers from the following evaluation criteria:

(1) Lustrousness of hair
An ionized air hair dryer has an ionized air blowing function. We confirmed the level of lustrousness by questionnaire for both current and ionized air hair dryers.

(2) Cost of hair dryer
We estimated the cost of current and ionized air hair dryers, and the value is expressed as a ratio, assuming that the cost of a current hair dryer is 100. The cost of an ionized air hair dryer is more than that of a current hair dryer, as it needs an additional mechanism for blowing ionized air, as shown in Fig. 6. The cost of a current hair dryer ranges from 95 to 105 (system range), whereas that of an ionized air hair dryer ranges from 98 to 108 (system range).

(3) Weight of hair dryer
We estimated the weight of current and ionized air hair dryers, and the value is expressed as a ratio, assuming that the weight of a current hair dryer is 100. An ionized air hair dryer is heavier than a current hair dryer, as it needs an additional mechanism for blowing ionized air, as shown in Fig. 7. The weight of a current hair dryer ranges from 97 to 103 (system range), whereas that of an ionized air hair dryer ranges from 99 to 105 (system range).

We assumed that there were two cases of requests for these evaluation items from marketing.

(Case 1)
Marketing is requesting a lustrous effect using ionized air blowing. They are requesting the same levels of cost and weight in the new hair dryer as those in current hair dryers. This means that the design range of cost is 100 or less.

(Case 2)
Marketing is requesting a lustrous effect using ionized air blowing. They are requesting 1% cost reduction from current dryers and the same weight in the new hair dryer. This means that the design range of cost is 99 or less.

4.2. Results of case study

Questionnaire results for the level of lustrousness with current and ionized air hair dryers are presented in Table 1.

Table 1.

Questionnaire results for lustrous level

Product	Questionnaire results		
	Satisfied counts	Not satisfied counts	Satisfied ratio
Current hair dryer	1	9	0.100
Ionized air hair dryer	8	2	0.800

I_T was calculated on the basis of the Case 1 marketing request, and the questionnaire results are presented in Table 2. I_T of the current and ionized air hair dryers are 3.689 and 3.624, respectively. This indicates that the ionized air hair dryer satisfies the Case 1 marketing request better since I_T of the ionized air hair dryer is less than that of the current hair dryer.

Table 2.

Results of Information value (Case 1)

Current hair dryer vs. Ionized air hair dryer		Evaluation value			Total information
		Lustrousness level	Cost	Weight	
Current hair dryer	System range		95–105	97–103	
	Design range		100 or less	100 or less	
	Common range		95–100	97–100	
	P_c	0.100	0.500	0.500	
	Information	2.303	0.693	0.693	3.689
Ionized air hair dryer	System range		98–108	99–105	
	Design range		100 or less	100 or less	
	Common range		98–100	99–100	
	P_c	0.800	0.200	0.167	
	Information	0.223	1.609	1.792	3.624

On the other hand, I_T was calculated on the basis of the Case 2 marketing request, and the questionnaire results are presented in Table 3. I_T of the current and ionized air hair dryers are 3.912 and 4.317, respectively. This indicates that he current hair dryer satisfies the Case 2 marketing request better since I_T of the current hair dryer is less than that of the ionized air hair dryer.

Table 3.

Results of Information value (Case 2)

Current hair dryer vs. Ionized air hair dryer		Evaluation value			Total information
		Lustrousness level	Cost	Weight	
Current hair dryer	System range		95–105	97–103	
	Design range		99 or less	100 or less	
	Common range		95–99	97–100	
	P_c	0.100	0.400	0.500	
	Information	2.303	0.916	0.693	3.912
Ionized air hair dryer	System range		98–108	99–105	
	Design range		99 or less	100 or less	
	Common range		98–99	99–100	
	P_c	0.800	0.100	0.167	
	Information	0.223	2.303	1.792	4.317

5. Conclusion

We proposed a new quantitative product planning approach using the TRIZ and IIM. This approach was based on the assumption that there is potential demand for new functions even if current products **do not h**ave the function. We decided to obtain potential requests for the new function from questionnaire data. Using this approach, the following points were confirmed.

1. Previously, even if a new function was created by TRIZ, it was difficult to compare current and new-function products. The new, proposed evaluation method makes it possible to quantitatively compare current and new-function products.
2. By calculating the common evaluation measures, “Information” from the probability of achieving a satisfaction level was obtained, which made it possible to conduct a quantitative comparison.
3. In the case study, we confirmed that a more satisfactory hair dryer is selected by quantitatively applying the proposed method to the different requests for lustrousness, cost, and weight in hair dryer improvement planning.
4. The proposed method will require an objective method for the evaluation of ideas created through TRIZ. In future, using this method with TRIZ, more effective product development will be possible.

Although we found it necessary to apply some subjective evaluation methods such as questionnaires, it is one of the characteristics of the IIM to evaluate without subjectivity. We expect that subjectivity will be reduced by a larger questionnaire sampling size in the future study.

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TRIZ*fest* 2015

ADVANCED FUNCTION APPROACH IN MODERN TRIZ

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Abstract

Advanced Function Approach (AFA) was introduced in 2010 at TRIZ Future Conference conducted by ETRIA. At that time, it was shown how utilizing the spatio-temporal parameters can further enhance such a powerful analytical tool as Function Analysis for Engineering Systems. Since then, AFA has proved its practical efficiency in dozens of TRIZ projects. Methodological recommendations for applying AFA have been developed and verified in the following areas:

- Specifics of Function Analysis for Engineering Systems at the exploitation stage (TRIZ Fest 2012);

- Revealing and describing the synergetic effect of combining two Engineering Systems (TRIZ Fest 2013);

- Novel approach to categorizing functions that Engineering Systems perform

(TRIZ Fest 2014).

Here we reflect milestones in developing Advanced Function Approach and incorporating it in Modern TRIZ. The main recommendations of AFA are also summarized in this paper.

Keywords: Function Analysis, Spatio-temporal Parameters, Advanced Function Approach.

1. Introduction

The history of developing function approach is described in detail in [1]. Nowadays, about twenty ways to define and utilize the concept of “function” in various fields of science and engineering exist. Those concepts are described and discussed in [2]. Results of extensive research on philosophical and methodological aspects of applying the function approach can be found in [3-5].

In this article we will focus on the practically oriented function approach which is used in Modern TRIZ for analyzing engineering systems.

Function analysis, as defined in Modern TRIZ, is an analytical tool that identifies functions, their characteristics, and the cost of System and Supersystem components [6]. This type of analysis is needed to identify the system's disadvantages such as harmful functions, insufficiently or excessively performed useful functions, excessive cost of components and, as was proposed recently, the wrong place and time of performing functions, and the absence of the required functions [1]. Another goal of Function Analysis is to prepare a model of the system to be used in the subsequent stages of the analysis: Flow Analysis, Cause-Effect Chain Analysis (CECA) or Root-Cause Analysis (RCA), Trimming, Feature Transfer, Super Effect Analysis.

2. Essence of Advanced Function Approach

1. The function analysis for engineering systems, as developed by specialists of the Leningrad (St. Petersburg) TRIZ school, Vladimir Gerasimov and Simon Litvin, is characterized with the following attributes:

- A concrete, practical definition of function was introduced: "An action performed by one Material Object to change or maintain at least one Parameter of another Material Object"

- A triad for the description of a function was suggested: "function carrier - action - object of the function"

- Rules and algorithm for accurately formulating functions were developed.

- A parametrical evaluation of the level of function performance was suggested

- Also, the concepts of harmful and neutral functions were introduced.

Graphically, a function can be represented as shown in Fig. 1.

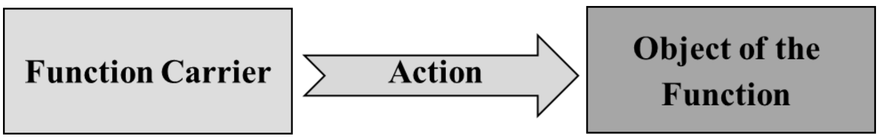

Fig. 1. A traditional graphical representation of function.

The specific steps and detailed procedure of the Function Analysis is described in Russian [6]. In English some highlights can be found in [1]. Formulating specific functions which is the last step of the Function Analysis can be performed according to the soft algorithm proposed in [6]: "there is a certain sequence to defining a useful function of a function carrier:

1. Suggest an initial formulation of a function that seems correct.

2. Ascertain whether the function carrier could perform the proposed function itself (the criterion for this is the presence of at least one element in the carrier that participates in the execution of the function).

3. Formulate a more precise definition of the function by asking the following questions: "what is the purpose of performing the function?" (if the element mentioned in #2 above is evident); "how exactly is the function performed?" (if the element in #2 is not evident).

If the initial function is imprecise, procedures 2-3 should be repeated until a precise definition is found. The criterion for finding a meaningful, precise definition is that at least one element of the object being analyzed takes part in performing the function."

AFA proposes adding the following steps to those above [1]:

4. "Indicate the place the function is performed;

The indication of place should be precise and specific, because the same function could have very different levels of performance in different places.

5. Indicate the time the function is performed."

These two additional steps seem simple, but they really help to understand the system and identify its disadvantages let us consider a case study presented in [1]:

Based on practical experience, AFA does not take much more time and effort than the classical Function Approach to analyze an Engineering System, but AFA does allow us to find the real non-obvious disadvantages of a system under analysis. Moreover, application of AFA significantly accelerates the subsequent analytical and problem solving procedures.

3. Specifics of Function Analysis for Engineering Systems at the Exploitation Stage

The exploitation stage for any system is the point where the system performs all of the useful functions for which it was designed. It is vitally important that the system performs these functions well and just how well it does this characterizes the overall performance of the system.

Actually, as was shown in [7], exploitation is a process and if we need to analyze the system at the exploitation stage of its life cycle, then we need to apply Function Analysis for Technological Processes which is more complicated than the Function Analysis for Products, it utilizes different rules and ranking of functions. On the other hand, we may use Advanced Function Approach in order to analyze the system at the exploitation stage.

Briefly, the recommendations for Function Analysis of a system at the exploitation stage could be summarized as follows:

- The Function Analysis should be performed at the highest hierarchical level; at the level of the Supersystem. When the system is at the exploitation stage, it is very important to take into consideration its interactions with the Supersystem's components, including the object of the main function – Target.

- Advanced Function Approach can significantly enhance the efficiency of the Function Analysis. In fact, if we apply the spatio-temporal parameters "time of performing a function" and "place of performing a function", we combine features of both Function Analysis for products and Analysis for processes.
- It is also recommended to perform a quick Function Analysis of the system at the exploitation stage, even if we consider any other previous or subsequent stage as a project scope:
- At a previous stage (manufacturing, transporting, etc.), such analysis will allow us to predict and take into account all further important interactions with the Supersystem.
- At a subsequent stage (storage, maintenance, etc.), such analysis will provide a list of actual resources that are available in the Supersystem.

In more detail the recommendations on how to perform the Function Analysis of a system at the exploitation stage can be found in [7].

4. Synergetic Effect Achieved when Two Identical Systems are Joined

Here we will demonstrate a practical example of applying Advanced Function Approach. More specifically, we will demonstrate how the Advanced Function Approach can be used to reveal and describe the synergetic effect of combining two engineering systems. According to a formal definition, "Synergetic (or Synergistic) Effect is an effect arising between two or more agents, entities, factors, or substances that produces an effect greater than the sum of their individual effects" [8]

The simplest scenario is when two identical systems are joined together [9]. When building a function model of such a bi-system, it is important to know the specifications for "when" and "where" each system in the bi-system performs its function. This will give us a clear understanding of what the best regime for the conjoined operation is.

Let us consider in detail how the synergetic effect can be achieved in the simplest case of combining two identical engineering systems. First of all, we need to consider all possible conditions in which the actions of the systems we are combining perform. Table 1 summarizes these conditions.

Table 1

Conditions of performing actions when combining two systems. Possible combinations.

		Temporal description of performing actions	
		Simultaneously	Sequentially
Spatial description of performing actions	In different places	1	2
	At the same place	4	3

Let us now consider how the expected results depend on the conditions of actions performed.

No.1: the results are additive, but they can be achieved in a shorter period of time.

No.2: does not lead to reducing the time needed to achieve the results; the results are simply summarized.

No.3: the result doubles, but the time for achieving this doubled result remains the same.

No.4: the time needed to achieve the result is reduced, but the value of this result strongly depends on the exact interaction of the two systems in the zone of co-action. That is, the systems could even impede each other.

So, in order to make an informative conclusion about the efficiency that can be achieved when combining two systems, the first step is to understand the spatio-temporal parameters of their functions.

In order to illustrate the above approach let us look through a case study. Imagine there are two identical excavators that are digging a ditch together. It is assumed that the ditch has a simple shape: its cross-section is rectangular and there are no turns along the ditch. The width of the ditch is equal to the width of one excavator bucket.

- *No.4:* if two buckets are directed into the same place simultaneously, then the result achieved is rather harmful.

- *Nos. 2 and 3* do not really make sense in this specific example.

- *No. 1* is the most interesting one. If the functions are performed in completely different places (i.e. the excavators dig from opposite ends of the ditch), the achieved results will simply be summarized. However, if both excavators dig simultaneously and the place where the functions are performed is properly organized, then a synergetic effect can be obtained. For example, the first excavator removes the ground from the upper half of the ditch and the second one removes it from the lower half, see Fig. 2. In this case we will dig the ditch more than two times faster since the excavators do not need to adjust the positions of their buckets along the vertical extend. So, each of them works more efficiently.

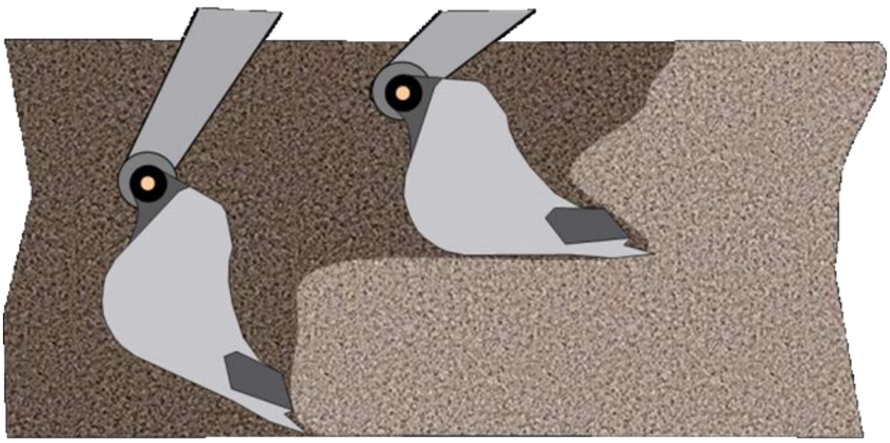

Fig. 2. Excavators joined into a bi-system.

But the opposite effect can also be achieved - when such separation of place (where the functions are performed) leads to increasing the total time of the operation. To work properly, each excavator should operate at its respective depth, and one excavator must remove ground from the ditch at a distance sufficient so as not to hinder the second. However, if the ditch is not long enough, there is no positive effect at all from combining the two excavators.

So, in order to reveal a synergetic effect and describe it in terms of functions, it is necessary to use the spatio-temporal parameters of actions. When two identical systems are combined into one system as discussed above, there was no way to explain the expected results without clarifying the two parameters "time of performing a function" and "place of performing a function". So, we have illustrated another important practical application of the Advanced Function Approach.

5. Approach to Categorizing Functions that Engineering Systems Perform

Function Analysis, as presents in Modern TRIZ, is one of the most developed and formalized analytical tools. However, a complete list of recommendations for selecting the most appropriate function(s) is still lacking.

The recent fundamental research published by Yury Fedosov [10] recommends "the most simple and obvious way of formulizing the procedure for formulating functions" is to choose the appropriate function for the current situation from "the list of elementary functions." This empirical study [10] is based on the representative statistical data taken from TRIZ consulting projects performed successfully in different engineering and scientific areas.

Another approach for formulating the functions of the system's components is based on the application of detailed algorithms. The first algorithm for formulating functions was proposed by Vladimir Gerasimov and Simon Litvin [6]. Recently, Alexander Kynin and Alexander Priven [11] developed an algorithm for selecting the elementary functions from the matrix 4x4x4, which simplifies and standardizes the procedure, thereby reducing the risk of erroneous formulations.

Hybridization of these two known approaches allows us to propose a novel approach for performing Function Analysis that is simple enough and not time consuming, but still sufficient for describing complex engineering systems and revealing their function disadvantages.

A hypothetico-deductive method of creating scientific theories is applied. This is when a whole working theory is built upon assumptions. Basically, this method organizes knowledge that existed before and extends the range of applications where that knowledge may be applied.

The novel approach described here is based on the two following statements:

- According to recommendations of AFA, the spatiotemporal parameters should be used when describing an Engineering System functionally: "time of performing a function" and "place/allocation of performing a function" in each specific situation. This leads to increasing the accuracy of the system description. Such detailed description allows us to identify function disadvantages in the system that are difficult to observe with the classical function approach.

- The original supposition is that the vast majority of functions that engineering systems perform can be covered by four base types of functions described in AFA format. The appropriateness of this supposition is supported by its testing with concrete empirical data.

Thus, we can formulate the main assumption: When the AFA format of function description is utilized, the vast majority of actions (the verb related part of a function formulation) can be described with the following verbs:

· ***To move*** (Note: when AFA format is applied the specification of direction, speed, distance is taken into account);

· ***To hold / to stop*** (Note: the final choice depends upon the initial stage of the function recipient. E.g., “to hold” can be applied if it was a stationary stage; “to stop” is more appropriate if the object was moving);

· To combine / to join;

· To separate / to divide.

Actions covered by the verbs above are general enough; they can be used for describing what any material objects (including substances and fields) do. This approach is illustrated in Fig 3.

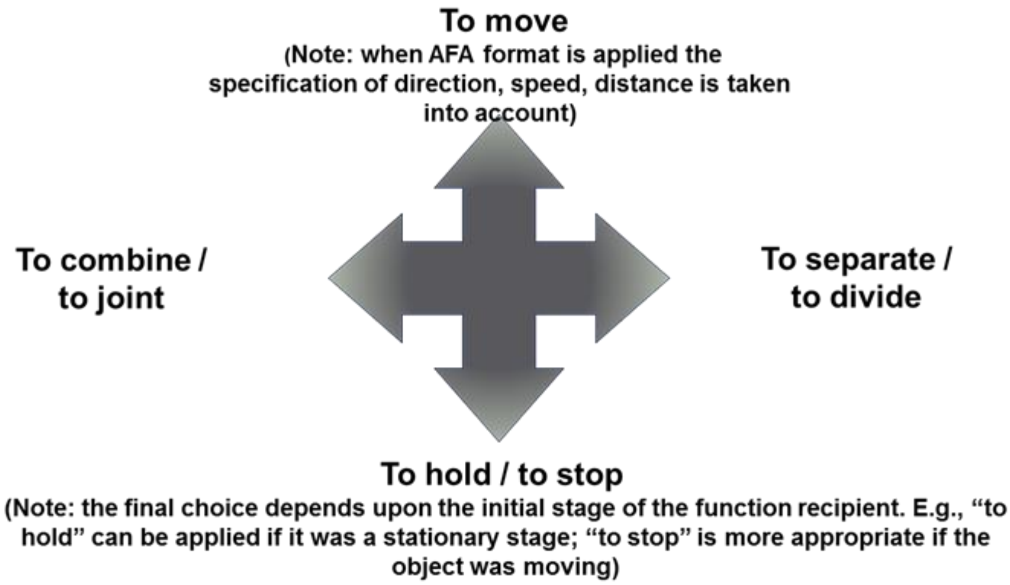

Fig. 3. Four Generalized Types of Functions.

At first glance the proposed approach may look oversimplified and insufficient for describing complex engineering systems. However, in our opinion it is sufficient because special attention is given to the parametric characterization of each function including its object, subject and action.

The first version of the “Elementary Functions” Handbook proposed in [10] has been used to validate the proposed approach. The Handbook is based on a statistical approach: 32 function models of actual complex engineering systems from different industries were analyzed. In total, 256 components performing 2132 functions were considered.

In fact, we substituted each function in the Handbook with one of the base/underlying functions proposed above and parameters of performing this function. More details of this research can be found in the recent publication [18].

Not only is the novel approach described here ready for application in actual projects, but it can also simplify introducing and explaining the function analysis to people who are not familiar with this analytical tool.

Basically, we can start with a general undefined description of the system we are analyzing. This will give us an initial understanding of the problem as seen by the client (a person or a project team) that owns the problem. Then, we need to create a function model by reformulating what the client knows using the set of base/underlying functions. Of course, all of the parameters of each function, including parameters of its object, subject and action, should be taken into account.

Since the number of base/underlying functions (actions) is limited by four types and seven verbs, creating the function model does not take much time. Actually, creating a function model can be performed together with the client in real time facilitation mode. The results of such facilitation can be vitally important for a complete final understanding of how the system works and what its function disadvantages are.

In general, the novel approach to categorizing functions is characterized by the following features:

- Simplified procedure and reduced time of the function analysis without compromising quality of its results;
- Ease of introducing/explaining the function analysis to people who are not familiar with this most important analytical tool in Modern TRIZ.

6. Conclusions

Based on an evolutionary analysis of the effectiveness of applying parameters for formulating functions, it was assumed that not only the object and the recipient of the function, but also the action (the verb) should be characterized by some parameters. It was suggested that the spatio-temporal parameters "time of performing a function" and "place of performing a function" are the most universal to characterize any action. In fact, any action takes place within a certain period of time and in a certain space. This approach was given the name "Advanced Function Approach".

Several applications of AFA have been developed since it was introduced in 2010. Those applications lead to increasing efficiency of analyzing Engineering Systems within TRIZ-based innovative projects. They allow TRIZ practitioners to identify system disadvantages that are hard to reveal using the Classical Function Approach.

Finally, we introduced a novel approach to categorizing functions that engineering systems perform. This makes the Function Analysis procedure simpler and, at the same time, enhances the value of analytical results.

Acknowledgements

We extend our sincere thanks to our colleagues - TRIZ developers who participated in discussions about function approach and importance of parameters for describing functions. Special thanks to Deborah Abramova who helped to make this paper sound more literate in English.

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APPLICATION OF PURPOSE AXIS AS A PART OF MULTI SCREEN THINKING

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Abstract

Multi Screen Thinking or 'Talented Thinking', was suggested by G. Altshuller in order that problem models may reflect the real world of the relevant problems. As for him, the world is complex, dynamic and dialectically evolving and then our models must be capable of treating such characteristics of the world. In his Multi Screen Thinking, Time Axis, System Axis and Anti System Axis were given to fulfil the requirements. Many additional Axes have been suggested during TRIZ development. Especially, N.Khomenko developed a variety of Axes of Multi Screen Thinking in accordance with his own OTSM viewpoint of problem model transformation to solve difficult problems. The axes of Multi Screen Thinking were not always originally novel but many of them had been used in other fields for the benefits of their own. That means new axes can be suggested if they can serve the essential roles of Multi Screen Thinking. This paper offers Purpose Axis as a part of Multi Screen Thinking. The author has gotten lots of benefits by considering purpose relationship among problems over some typical application of TRIZ. Purpose Axis will be discussed on its usefulness and applicability to engineering problems like patent design-around and business problems like blue ocean creation.

Keywords: Multi Screen Thinking, Talented Thinking, Purpose Axis.

1. Introduction

According to Souchkov, V., 'Multi Screen Thinking' is known to have originally the name of 'inventive system thinking'[1]. As for many TRIZ beginners, Multi Screen Thinking has been called 'Nine Windows Thinking' which the author believes might have been causing some misunderstanding how to use Multi Screen Thinking. The number of 'Windows' or 'Screens' is not an important feature when we deploy and use Multi Screen Thinking.

Multi Screen Thinking was introduced by TRIZ founder, G. Altshuller who called it 'Talented Thinking' [2-3]. According to him, when we make models which reflect the world of our problems, we should follow 'Talented Thinking' in order to reflect the world correctly. He said the world is complex, dynamic and dialectically evolving, so that our models from our consciousness must be the same in order to solve our problems. His ‘Talented Thinking’ seems to provide at least three axes composed of Time Axis, System Axis, and Anti System Axis along which we can imagine the evolution of a system. Briefly, Altshuller suggested it as a thinking method for correct description of the world relevant to our problems.

One of the popular modern versions of Multi Screen Thinking is ‘System Approach’ named by Ideation TRIZ experts [4-5]. ‘System Approach’ has the newly-added axes: ‘Cause-Effect’, ‘Input-Output’ and does not give serious attention to Anti System Axis. Ideation TRIZ experts explain that ‘System Approach’ is ‘multi-dimensional creative thinking’ and the unique ability of an inventor to look beyond the system as an object. Therefore, they believe ‘System Approach’ is a tool for changing the way you think.

N. Khomenko provided ‘OTSM Advanced Schema of Powerful Thinking’ as the advanced version of Multi Screen Thinking which has new axes more than five such as ‘Abstraction’, ‘Objectiveness’, and ‘Impossibility’, etc [6-8]. According to Khomenko’s viewpoint, the advanced Multi Screen Thinking offers the factors to transform the problem models for solving problems. He classified the axes into the groups like ‘reality viewpoint’ and ‘imaginary viewpoint’. The number of the groups would increase from his viewpoint.

There have been several new approaches introducing new axes and applying Multi Screen Thinking to Cause Effect Analysis for increasing the effectiveness of the analysis[9]. Pesetsky, etc. and Leonid Batchilo, etc. introduced Multi Screen Thinking with ‘Operation Axis’ as a way to improve Root Cause Analysis [10-11]. H. Yoon introduced ‘Occasion Axis’ as an additional new axis to examine the problem situation according to evaluation parameters and relevant control parameters [12-13].

In summary, Multi Screen Thinking has been developed for the following aims:

to reflect correctly the world of our problems;

to change the way you think;

to offer the factors to transform the problem models in order to solve difficult problems;

to analyse the problem situation more effectively.

Based on experiences of the author’s own, those aims have been fulfilled with applications of Multi Screen Thinking. The author believes that those aims are never completely and entirely achieved and have to be supported by continuous researches based on real cases.

The above discussion on the aims of Multi Screen Thinking leads us to the ways to add new axes. Through the history of Multi Screen Thinking, almost all of axes are not of ‘original novelty’. They are adopted from already-known and essential viewpoints, such as Time, Causality, Input-Output, and Abstraction axis, etc. Therefore, original novelty is not one of the requirements to be one of axes of Multi Screen Thinking. If there is a certain viewpoint required to be a part of Multi Screen Thinking according to the aims as pointed out earlier, we may as well consider it as an additional axis of our thinking directions. This paper resulted from that prospect. The author already suggested ‘Purpose Axis’ as one of effective thinking directions and shows some cases of its application. This paper discusses 'Purpose Axis' as a new additional axis of Multi Screen Thinking and effective use of it over various fields.

2. Purpose Axis and its applications

2.1. Definition

Purpose Axis is an axis along which the purpose level of a certain event changes, where an event is an entity in a certain state or an interaction between entities. Along Purpose Axis, we can identify 'different events of relatively different purpose levels' as shown in Fig. 1. The author believes that Purpose Axis must be distinguished from 'Why Question Series' like 5-Whys or 10 Whys, whatever. The 'Why' question may confuse us about the true meaning of it, 'Purpose' or 'Cause'.

From the ancient ages, 'Purpose' has been an important aspect of understanding things. One of the oldest quotes, the words of Gautama Buddha is known as "Your purpose in life is to find your purpose and give your whole heart and soul to it" [14]. Therefore, purpose viewpoint is not novel but embraced because of its usefulness, so that Purpose Axis has been adopted by outside of TRIZ field [15-16]. As for TRIZ field, The author first introduced Purpose Axis to formulate contradictions and improve the ways to overcome them [17-18]. The following sections are supposed to explain the already-developed applications of Purpose Axis to show it as a part of Multi Screen Thinking according to the purposes of Multi Screen Thinking discussed earlier.

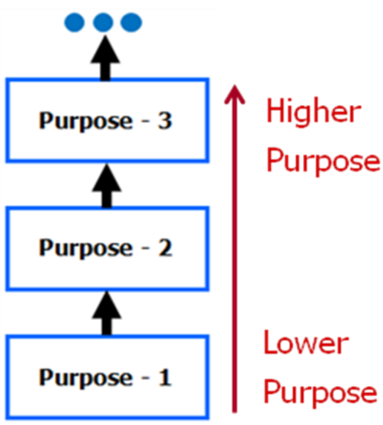

Fig. 1. A schematic explanation of Purpose Axis

A purpose of an event can be described by a state occasion or an interaction. For example, a filter mask is put on the face in order to block dust, which is shown as below:

higher purpose level – we want to block dust;

lower purpose level – we want to wear a filter mask on the face.

However, the purpose relationship is not always one between an object and something beyond it. Sometimes, certain parameters of the same thing have the purpose relation with each other. For example, we want to heat a gas in order to increase volume of the very gas.

Purpose Axis has been applied to several different problems by the author: to extract the initial problem out of the initial situation; to reformulate technical contradictions for resolution of them; to generate ideas for patent design-around; to search for alternative industries for creating Blue Ocean. The following sections are concerned about each of them.

2.2. A guide to extract the initial problem out of the initial situation

This application has been developed mainly to help analyse the problem situation more effectively. In general, the ‘difficult’ problem situation is composed of many trials for resolving a certain unsatisfied situation and the problems out of the trials. The solvers are facing not the first problem situation but the set of trials and problems from the trials.

Fig. 2 shows a typical case of the above situation. The solver might perceive ‘the first seeming problem’ as what he/she should solve. However, if the problematic situation has a long history of many trials, it should be analyzed to clarify the relations among trials to get the whole picture of the problem situation. In Fig. 2, ‘Purpose’ corresponds to ‘what we want to achieve’ through our trial. If we have been doing many trials with different purposes, the initial problem situation might be composed of a network of purposes relevant to the problem solving history. Purpose Axis helps to analyze the history of our problem solving. Additionally, before application of System Axis and Time Axis of the classical Multi Screen Thinking to this situation, we have to identify which system must be dealt with as ‘System’. Purpose Axis can be used as a part of Multi Screen Thinking for identification of the starting problem formulation from the initial problem situation and ideation of other solution ideas.

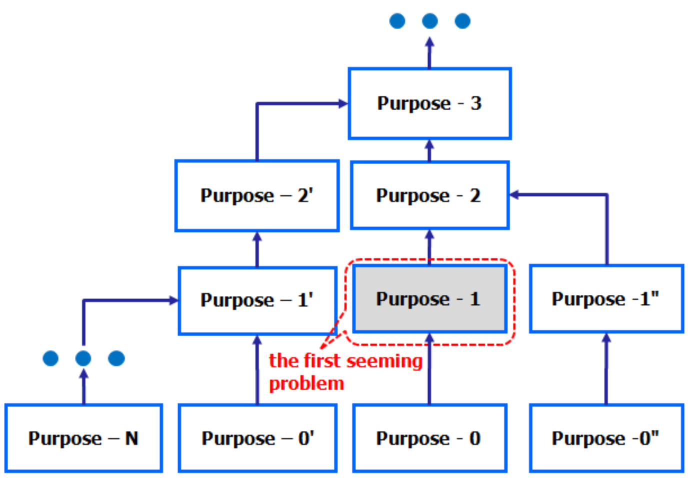

Fig. 2. A schematic of Purpose Axis application to the initial problem extraction

2.3. A guide to reformulate technical contradictions for resolution of them

Purpose Axis can guide a problem solver to reformulate technical contradictions to resolve them, which has been discussed with development of relevant themes like contradiction formulation and Cause Effect Chain Analysis. The benefits from Purpose Axis explained in those earlier works can reach more general cases. When we find difficulty in overcoming technical and physical contradictions, we may come up with resolving ideas by changing technical contradictions along Purpose Axis. Fig. 3 explains schematically how to transform a technical contradiction into a new one by changing the improving parameter of the original technical contradiction along Purpose Axis. 'A certain event' corresponds to a physical contradiction. The red and blue links from it with the deteriorating parameter and the improving parameter indicate the relation as a technical contradiction. If you cannot come up with any idea to resolve the contradiction with the left initial contradiction, you may try to reformulate your contradiction into new one by selecting the improving parameter on the higher purpose level along the Purpose Axis. The reformulated contradiction might be resolved to result in the same benefits that you wanted to achieve with the initial contradiction.

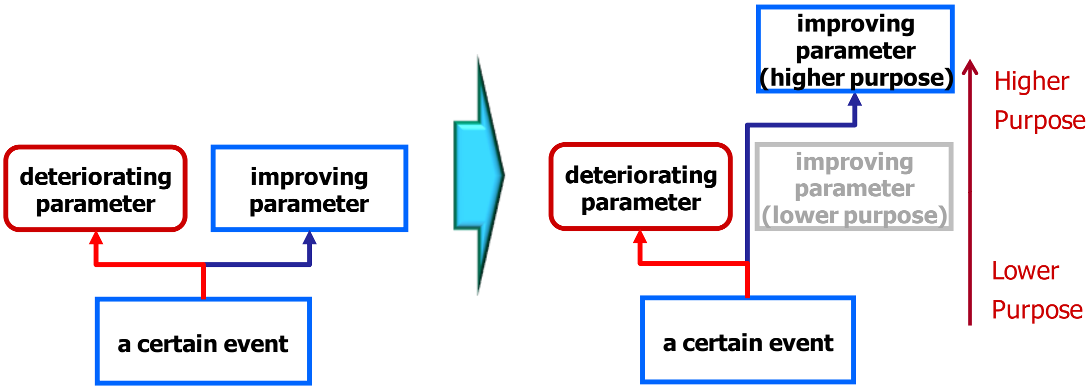

Fig. 3. A schematic of Purpose Axis Application for contradiction resolution

2.4. A guide to generate ideas for patent design-around

Patent design-around is offered in order that, at least, the same benefits are given by using certain approaches from considering those of the 'design-around' victim patent while avoiding patent infringement. Generally, avoiding patent infringement must be done in consideration of 'All Elements Rule', 'Doctrine of Equivalents' and 'Prosecution History Estoppel' [19-21]. The author suggested that Purpose Axis can offer idea directions to avoid patent infringement in line with 'All Elements Rule' and 'Doctrine of Equivalents' [22].

If we can deploy higher purposes of 'Elements' of the independent claims along Purpose Axis, we are able to formulate new problems: how to achieve the higher purposes without the 'Elements' of the independent claims in order to avoid patent infringement according to 'All Elements Rule'. Additionally, we can also formulate new problems: how to achieve the higher purposes and some additional benefits without the characteristics described in the independent claims in consideration of 'Doctrine of Equivalents'.

For example, let's suppose that we want to design around US 5954374A that was of a real project even if a patent was yet not granted for. It has several independet claims and the claim 1 is chosen for our discussion. US 5954374A relates to improvements in pipe connectors, especially for use of connecting metal pipe sections of a pipe string in the oil industry[23]. More particularly, the invention relates to improvements in the type of pipe connector. For brevity, the following part is extracted from the claim 1:

... means for supplying hydraulic fluid under pressure between the overlying parts of the surfaces of the members when fully engaged together to at least one of expand the box member and contract the pin member so as to bring the projections out of engagement with the corresponding grooves and permit the members to be disengaged; ...

If we analyze this long and complex description through Purpose Axis shown in Fig. 4, we may get the directions of ideas for patent design around in line with 'All Elements Rule' and 'Doctrine of Equivalents' without a lot of futher work including Function Analysis or Cause Effect Chain Analysis.

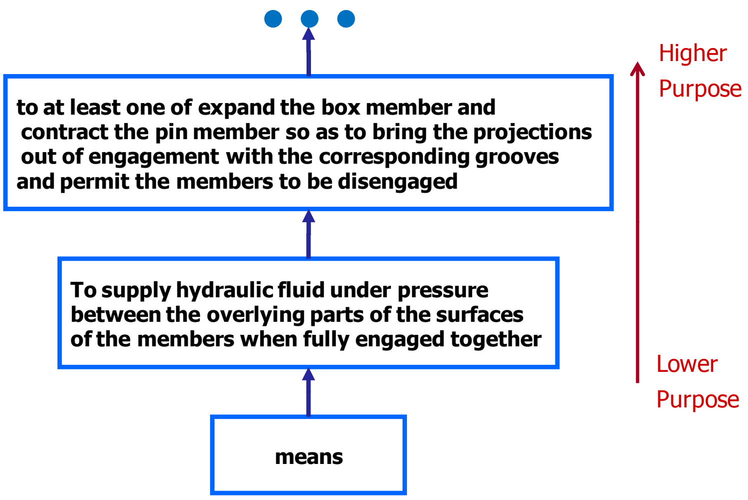

Fig. 4. Purpose Axis Application for the part of the target patent claim 1

If the highest purpose can be achieved without the lower level purpose which requires the means, we can at least avoid the patent infringement according to 'All Element Rule'. If the same approach results in new ideas which can bring additional novel benefits with a certain intensity that shows a clear difference from the target patent, we probably avoid the patent infringement according to 'Doctrine of Equivalents' because we adopt different ways or functions from the target patent by removing the lower level purpose which is a way or function of the target patent.

2.5. A guide to search for alternative industries for creating Blue Ocean

Blue Ocean Strategy offered a systematic way to develop the concepts of new industries, services, or products[24]. In 2006, the author suggested integration of Modern TRIZ thinking methods and Blue Ocean Strategy. Following Blue Ocean Strategy, we reconstruct the market boundaries for identification of commercially compelling blue ocean opportunities. The reconstruction is supported by ‘six paths framework’. The author insisted that Multi Screen Thinking can provide more other paths or more concrete paths than the six ones of Blue Ocean Strategy. Purpose Axis is one of those from which we can examine ‘Alternatives’ in order to reconstruct the market boundaries.

Let’s think about ‘noodle restaurant’ as our initially-considered industry. A usual market analysis based on ‘NOT-Blue Ocean Strategy’ might consider ‘other noodle restaurants’ as competitors because it focuses on being the best within ‘the very industry’ of similar ones. From Blue Ocean Strategy, we must think about ‘alternatives’ by looking across the industries. Typically, alternatives have different functions and forms but ‘the same purpose’. The author suggests that the meaning of ‘the same purpose’ must be extended to ‘along Purpose Axis’ because the purpose of a certain industry cannot be identified without considering the relative levels of purposes. For example, the purpose of ‘noodle restaurant’ could be chosen among ‘to fill one’s stomach’, ‘to nourish people’, or ‘to promote one’s health’, etc. Fig. 5 presents the purpose candidates along Purpose Axis for looking across the industries.

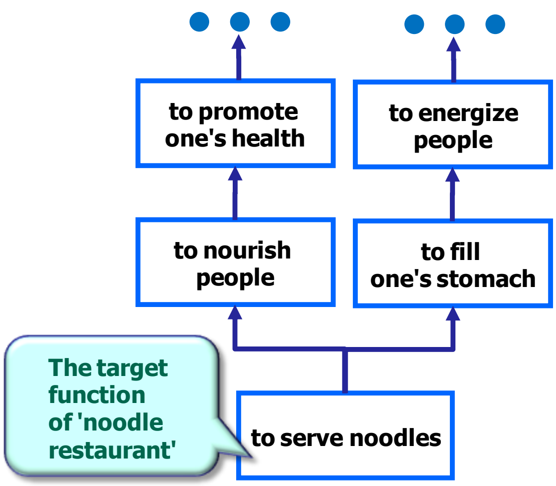

Fig. 5. A schematic of using Purpose Axis for looking cross industries

3. Conclusions

Multi Screen Thinking has been updated through the history of TRIZ. Additional Axes have been suggested in line with the requirements of axes of Multi Screen Thinking. According to these points, the author offered Purpose Axis as a new one of them because of its importance and usefulness during problem solving.

Purpose Axis can reflect correctly the world of our problems and change the way you think and transform the problem models in order to solve difficult problems.

By the author, Purpose Axis has been applied to extraction of the initial problem from a complex initial problem situation, technical contradiction transformation to resolve contradictions, patent design-around, and integration of Blue Ocean Strategy. It has resulted in successful cases for big Korean companies like Samsung, LG, Hyundai Motors, POSCO, and so on since 2002.

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APPLYING SYSTEM THINKING IN EVOLUTIONARY TRENDS

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Abstract

Evolutionary trends is one of the most promising fields in TRIZ where a lot of people are putting a lot of research efforts in. Current research mainly focuses on finding new evolutionary trends and application of evolutionary principles in different areas. However, evolutionary trends only explains the different possibilities that could happen in the future, while the area of defining which possibility is most probable is still a field that is not fully covered yet. This article explores the possibility of further applying system thinking in technological system evolution and uncovering the internal dynamics for technological system evolution. More specifically, this article explores the following three aspects for the technological system evolution: traction forces that generate new variants and moves technological system forwards along evolutionary trends; constraint forces that prevents technological system from generating new variants; selection forces that presides which variants are replicated and widely adopted. After exploring the different forces inside the technological systems, this paper establishes a new model to predict the emerging technologies across different industries. This initial theoretical research implies new opportunities in finding the new patterns inside technological systems that explains and predicts the advancement of new technologies. The intention is also to draw attention to this field of further articulation of technological system evolution.

Keywords: system; engineering trends; evolutionary tension; technology forecasting.

1. The basic structure of a system.

Systems thinking studies systems from the perspective of the whole system, focusing on the relationships and patterns in the relationships between the components or subsystems. At its simplest, a system is something composed of parts but which adds up to more than just these parts. There are 3 basic elements for a system: Purpose; components and relationship between components.

In an engineering system, there are 3 key elements: main function of the engineering system; subsystems or components; and the key mechanism of the system. The key mechanism defines how does energy transformed into the main functionality, for example, heat engines, including internal combustion engines and external combustion engines (such as steam engines) burn a fuel to create heat, which then creates a force. Electric motors convert electrical energy into mechanical motion.

2. Ideality and Relative Ideality.

Henry Altshuller, considered to be the father of TRIZ, defined ideality as an equation where the numerator is a sum of all useful functions performed by a system and the denominator is the sum of all undesired effects associated with the system [1]. Any form of cost, including labor, materials, tests, waste, injuries, and ecological damage, is included in the undesired effects. Changes to a design that increases the numerator and/or decreases the denominator are said to bring the system closer to ideality [1].

Altshuller arrived at the conclusion that the ideal system performs a function without actually existing [1]. Practically, the ideal system is an unobtainable goal, but we can try to approach it.

Ideality is the measure of how close a system is to its best situation, i.e. its ideal final result (IFR) [2,3]. Ideality of a system can be expressed in mathematical terms as:

$$Ideality = \frac{\sum Benefits}{\sum Costs + \sum Harms}$$

One of the main evolutionary trends for engineering system is to increase ideality. As the above equation indicates, this can be achieved by increasing the benefits provided by the system or reducing the costs, or reducing the harmful functions that come with the benefits.

Engineering trends are the patterns of evolution representing the trends that document strong, historically recurring tendencies.

IFR defines the goals or the solution requirements of the problem. It also helps to determine the optimum resources to use in delivering the functions of the system and recognize the constraints of the problem to be solved [2].

However, the system will not probably jump to the ideal final result directly. Sometimes the system does not evolve along the way it “should” be. For example, the ideal final result for knife and fork should be less expensive, even with some field like laser to exert the function of cutting, but it does not evolve along this way. The reason for this is that for any innovation to take place in a system, there is a creative destruction process. And it takes energy to destruct. And achieving different level of ideality requires different amount of energy.

Based on the basic structure of a system, increasing ideality is achieved by any of the three types of improvement: Improvement of the ideality in a subsystem; improvement of the coordination among subsystems and super systems; improvement of the ideality in the key mechanism of the system. For example, if we want to improve the ideality of a lamp, there are 3 types of improvements: improvement of the subsystems, such as the bulb, the electrical wires, etc.; improvement of the coordination among subsystems and super systems, such as better control of bulb or adjusting the lighting based on the natural lighting in the environment, etc.; improvement of the key mechanism, such as changing from incandescent lamp to LED lamp.

For different types of improvements, the constraint it will have to overcome is different. It is relatively easy to improve the bulb, but very difficult to invent a new mechanism for lighting.

3. Dominant Variant.

At any given time, there are multiple directions towards which the engineering system could evolve into, and there are multiple variants of the system that may emerge. Then what are the key factors that determines the direction of the evolution and the selection of the dominant variant?

In early work, Utterback and Abernathy [4, 5], and Sahal [6] argued that industries tend to shift from an initial stage of product design experimentation by firms to a stage featuring process innovation aimed at cost reduction. At some point, this experimentation leads to the emergence of a ‘dominant design’, defined as ‘the concepts that define how the components of the product interact or relate to each other’[7].

The Variation-selection-Dominance dynamic is due to standardization and scaling up. Along with the scale-up of a certain variation, the cost for manufacturing is decreasing, but the cost for switching is increasing. Once the dominant design is established, competition based on economies of scale and incremental, component-level innovation.

4. Evolutionary tension.

Why does engineering system evolve towards a certain direction? Behind any innovation, there is a passionate innovator who overcome all kinds of obstacles and make things happen. When the innovators are improving the engineering system, they are driven by the force of creative tension. Creative tension was coined by Robert Fritz in his book, *The Path of Least Resistance*. Creative tension is the energy that is created when people have a clear picture of the desired vision (what we want) and the current reality. When we become aware of the gaps between where we are and where we want to be, we have a natural tendency to seek a resolution between the two. So creative tension is the tension between the pulling forces of the vision and the obstacles from the current reality.

From a bigger point of view, the engineering system evolution is driven by the collective creative tension of the whole society. The bigger the tension is, the higher the probability of evolving to a certain direction will be. We define the tension that determines the direction of engineering system evolution as evolutionary tension.

The evolutionary tension is influenced by three factors, the traction forces that pull the engineering system to evolve, the constraint forces that prevent the engineering system from evolution, and the selection forces that significantly amplify the pulling or constraint effect.

The engineering system will evolve towards the direction with the most intensive evolutionary tension.

Traction Forces are the forces that move the system forward, including traction forces from the potential effects; traction forces from the customer demand; and traction forces from competition.

Potential effects defines the potential benefits or impacts that the potential evolution will bring to the market and society.

Customer demand defines the interest from the current customer base.

Competition defines the possibility that the evolution variation will be replaced.

Constraint forces are the forces that prevent the engineering system from evolution, including the constraint forces of the main mechanism, the constraint of coordination, the constraint of resources

Constraint of the main mechanism defines the constraint brought by the key mechanism of the system. For example, the precision of the microscope is restricted by the wavelength of light.

Constraint of the coordination defines the coordination among subsystems and between the system and supersystems.

Constraint forces of resources defines the resources available in the system and supersystems.

Selection forces are the external forces that will significantly amplify or inhibit the system to evolve, including investment, Government Policy, etc.

$$\mathrm{ET}=\frac{\mathrm{TF}}{\mathrm{CF}}\times\mathrm{SF}$$

(ET: Evolutionary Tension; TF: Traction Forces; CF: Constraint Forces; SF: Selection Force)

5. Evolutionary tension evaluation method for different variants.

How to evaluate evolutionary tension? If we set a value to each factor that contributes to the evolutionary tension, then we could quantify the level of evolutionary tension and compare the evolutionary tension of different variants. To specify, traction forces include traction force from the potential effects; traction force from the customer demand; and the traction force from competition. And the constraint forces include the constraint force of the main mechanism, the constraint force of coordination, and the constraint force of resources.

$$\mathrm{ET}=\frac{T_{PE}+T_{CD}+T_{C}}{C_{M}+C_{C}+C_{R}}\times\mathrm{SF}$$

(ET: Evolutionary Tension; T_{PE}: Traction Force-Potential Effects; T_{CD}: Traction Force-Customer Demand; T_C: traction forces – competition; C_M: Constraint Force-Main Mechanism; C_C: Constraint Force-Coordination; C_R: Constraint Force-Resources; SF: Selection Force)

To make it more distinguishable, we set the value with the following criteria:

Table 1

Criteria for evaluation of evolutionary tension

	Weak		Medium		Strong	
	Criteria	Score	Criteria	Score	Criteria	Score
Traction Force-Potential Effects	Less than 50% performance improvement	1	50% to 100% performance improvement	3	more than 100% performance improvement	9
Traction Force-Customer Demand	It does not create much values for customers	1	It creates values for customers, but it's not quite perceivable	3	It's ideal for the customer, and they are willing to pay extra money	9
traction forces - Competition	Probably there will not be any variant of this kind launched to the market in 6 months	1	There are some competitors who are going to launch the variant to the market in less than 6 months	3	There are some competitors who have already launched this variant to the market, and it's quite successful	9
Constraint Force-Main Mechanism	Level 1 or Level 2 invention needed	1	Level 3 invention needed	3	Level 4 invention needed	9
Constraint Force-Coordination	Existing supersystem already in align	1	Existing supersystem needs minor modification	3	Existing supersystem needs significant modification	9
Constraint Force-Resources	No constraint of resources in the system	1	Minor constraint of resources in the system	3	Significant constraint of resources in the system	9
Selection Force	Significant obstacles from investment or government policy	1/3	Neutral	1	Significant promotion from investment or government policy	3

Basically, the higher value the evolutionary tension is, the more worthwhile to develop the variant. If the value of evolutionary is higher than 3, then we suggest to invest intensively to develop the variant in short term. If it's less than 1, then we suggest not to pursue this variant. If it's between 1 and 3, then we suggest to put it on the mid-term and long-term development roadmap.

6. Technology forecasting algorithm.

With the abovementioned concepts, we developed a new algorithm for technology forecasting. The technology forecast mainly address the following question: whether a new technology will become the dominant variant; What are the major bottlenecks and when will they be broken; The impact to the economy and society; The impact to the evolution of other engineering systems.

The Main steps of the algorithm include:

Step 1. Function Analysis.

Step 2. Define the possible variants based on the engineering trends.

Step 3. Analyze the evolutionary tension.

Analyze the traction forces.

Analyze the constraint forces.

Analyze the selection forces.

Step 4. Define the future technology development map based on the evolutionary tension.

7. Example: technology forecast for air purifiers

Step 1. Function analysis.

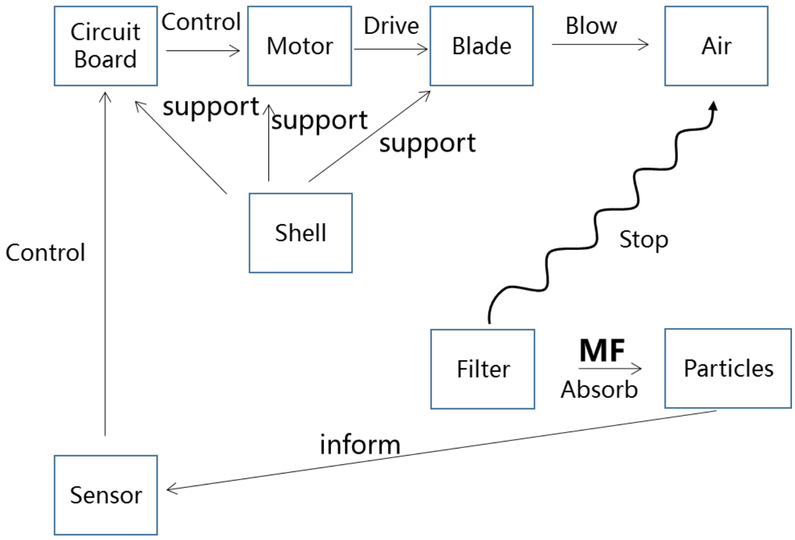

Fig. 1. Function analysis of air purifier.

Step 2. Define the possible variants based on the engineering trends.

Through brainstorming using the engineering trends, we could generate different possible variants. For example, using the trend of transition to the supersystem (subtrend-increasing differentiation between main functions: allied engineering systems), we identified the variant of Air cleaner with the function of humidification, dehumidification and cleaning and air purification membrane; using the trend of increasing coordination (subtrend-coordinated actions), we identified the variant of filter with spherical shape and filter with different layers; using the trend of increasing controllability (self-controlled system), we identified the variant of auto-start mode if the PM 2.5 value (air quality parameter) is higher than a pre-set value.

Step 3. Analyze the evolutionary tension.

Following the criteria in Table 1, we calculated the evolutionary tension based on the equation of evolutionary tension.

Table 2

Example of air purifier: Evaluation scores of evolutionary tension

	Air cleaner with the function of humidification, dehumidification and cleaning	Filter as a screen of window	Air purification membrane	Filter with spherical shape	Filter with different layers	Auto-start mode if the PM 2.5 value is higher than a pre-set value
Relative Reality	Relative Ideality Level 1	Relative Ideality Level 2	Relative Ideality Level 3	Relative Ideality Level 1	Relative Ideality Level 1	Relative Ideality Level 2
Dominance State	Variation	Variation	Variation	Variation	Variation	Variation
Traction Force-Potential Effects	1	9	9	3	3	3
Traction Force-Customer Demand	3	9	9	3	3	9
traction forces - competition	3	1	1	3	3	3
Constraint Force-Main Mechanism	1	1	9	1	1	1
Constraint Force-Coordination	3	3	9	1	1	1
Constraint Force-Resources	1	3	3	1	1	1
Selection Force	1	1	1	1	1	1
Evolutionary Tension	1	3	1	3	3	5

Step 4. Define the future technology development map.
Based on the analysis, we selected the following variants as candidates for further development: Filter as a screen of window; Filter with spherical shape; Filter with different layers; Auto-start mode if the PM 2.5 value is higher than a pre-set value. Then we put these candidates for development in the technology roadmap. We use the constraint forces to determine the timeframe. If the constraint forces are very small, then we put them in short term, and if the constraint forces are big, then we put them in middle term. So we put the different items in the simplified version of development roadmap:

Table 3

Example of air purifier: simplified version of technology roadmap

Year 0-2	Year 3-5
Filter with spherical shape	Filter as a screen of window
Filter with different layers	
Auto-start mode if the PM 2.5 value is higher than a pre-set value	

8. Conclusions and recommendations.

The original algorithm for evolutionary tension analysis presented in this paper has revealed so far an adequate applicability to different engineering systems in different industries. As a result it is possible to build with systematic and repeatable steps for technology forecasting, roadmap development, and portfolio management.

Compared with TRIZ-based forecasting approaches published in literature, the authors have focused on the analysis of the traction forces, constraint forces and selection forces to determine the probability.

The author is further developing the proposed algorithm with the aim of taking into account the analysis of more comprehensive analysis to generate all possible variants and directions for engineering system evolution. Thus, the process itself as a whole is considered as a methodology to forecast all the possibilities and which has a higher probability to become the dominant variant. A further direction for investigation is the better way to evaluate the evolutionary tension. Also, application of this approach in different industry context would be valuable.

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APPLYING TRIZ ACROSS COMPANIES

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Abstract

TRIZ is a very powerful tool for innovation generation. In the last years this method has spread across industry and revolutionized innovative thinking.

Industrial reality is up to now often organized in a way that engineers follow processes that cover the span from idea to maturity of a product. In that time span only a short piece is using TRIZ to generate ideas systematically. The major part is compiling the boundary conditions that are seldom of physical nature and evaluating and then demonstrate, prototype and finally design the mature product. Considering a development time of average about 2 year for a complex part, only very few times TRIZ is used, mostly as brainstorming aid tool in the concept phase or occasionally when specific problems arise during project execution.

TRIZ is a tool that needs to be trained and continually used in order to make most use of it. If working conditions do not allow this, one has to search for other ways to realize this. This paper shows how a solution was found to work the conventional way industrial processes are operated and at the same time keeps up using TRIZ continuously and in surplus to widen one's technological knowledge.

The solution is to set up a group of TRIZ knowledgeable persons from different institutions and to periodically set up meetings at the different facility sites to solve a company specific problem for which no IP or competition issues are present with TRIZ tools. This kind of open access innovations keeps up TRIZ application and trains its usage, it is fun, serves widening of technology knowledge and comparing different application approaches, enables learning from other innovators and sets up a network.

This paper is a report on an example of application of TRIZ effectively in a company and cross companies. It is not targeted to add novel contributions to the TRIZ methodology, rather to introduce new frameworks for application.

Keywords: TRIZ, heterogenic groups, cross companies working, learning TRIZ, innovation method.

1. Today's situation

When dealing with complex hardware challenges, companies have processes in place on how to best develop the technology and to solve problems. At GE for example we have been using SixSigma as a methodology for decades. Design for SixSigma (DFSS) is a great process for the complete hardware development, dealing from the initial goal (not a problem to solve) until a mature product dispatch. The SixSigma process looks at defining the task explicitly, defining customer pain points and needs, looking at a team charter, etc. The "measure" step is for identifying how the system shall be measured and how success is defined. In "analyse" we look at the system and tasks in order to design and optimize a solution. This is checked against the requirements in the "verification" step.

SixSigma is very powerful in structuring this development process. However when it comes to generating solutions for a problem, it provides weak suggestions. In this space TRIZ is the valuable tool (Fig. 1).

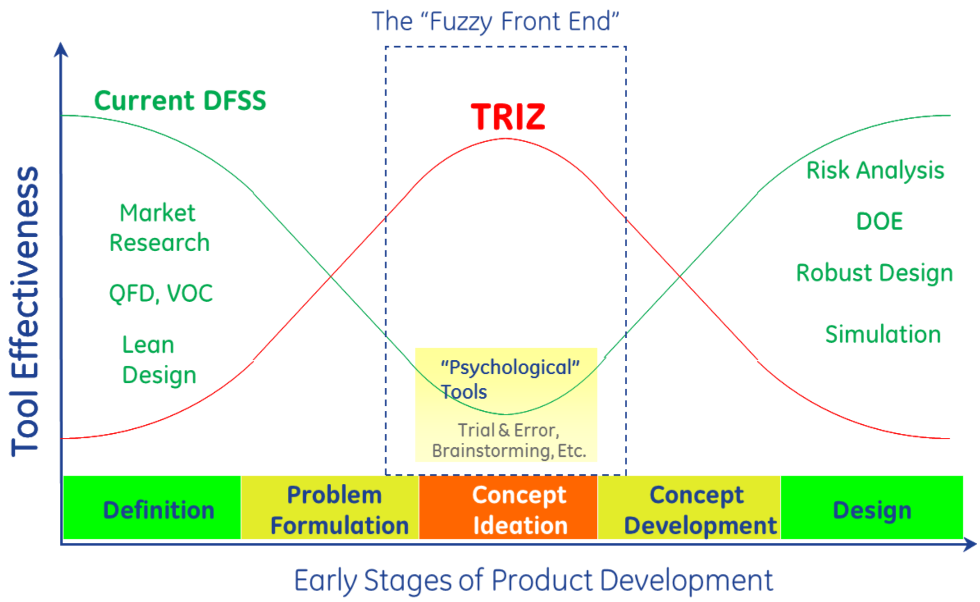


Fig. 1: Tool effectiveness of SixSigma and TRIZ over the product development stages

(Source: Adapted from *Risk Free Business Innovation*, Mark Barkan, 8/5/2006, [3])

This approach however limits TRIZ adoption within a team, with the effect that it is only used during a short time and for short tasks. But this is not the most effective usage for the TRIZ toolbox, since TRIZ is not only a methodology for generating breakthrough solutions in a shorter time, rather it is a mind-set. Using TRIZ on a regular basis in daily work reshapes the way of thinking, of approaching and seeing technical solutions. This is at least the experience that we gained in GE Global Research looking at the projects performed and the people that are using TRIZ. But as we know from psychology [1], it requires continuous application of TRIZ thinking in order to change the mind set and approach to problem solving, boost creativity and overcome psychological inertia. Practising creativity is instrumental: the peak point of creativity lies during childhood, where indoctrination with knowledge is not yet so extreme and only starting at school (Fig, 2).

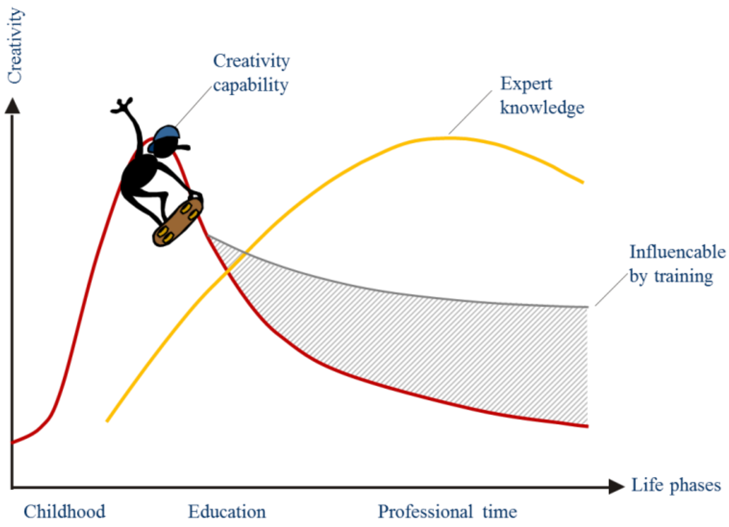


Fig. 2: Creativity evolving over time

[Source: Adapted from *Innovationen Systematisch Erarbeiten, Uwe Metzger*]

The more knowledge people gain, the more creativity declines. In this case people become the well-known experts in a field, with the side effect that solid experience tends to impair creativity with their experience on "what does not work". Still the level of creativity can be influenced by training and practise. The more someone is involved in working creatively, the less he will be influenced by his experience. One way to achieve this is to promote regular application of TRIZ. We solve the problem of increasing TRIZ adoption in a corporate environment to enhance capability using TRIZ itself.

2. Approach to a Solution

Looking at the situation we can apply TRIZ and find the following main contradiction:

IF scientists use TRIZ only in the inventive problem solving phase of a project
THEN the product will be developed to maturity
BUT scientists are not continuously trained in TRIZ and don't change their inventive capabilities

This can be (amongst others) translated into improvement of productivity and worsening of reliability. The suggested principles are: Segmentation, Parameter Change, Pneumatic / Hydraulic and Oxidation.

2.1. Translation of Principles into Specific Solutions

A brainstorming was done on how to translate the suggested principles into specific solutions. The major ideas generated were:

- Define a dedicated team that only gets active in the inventive problem solution phase but for different projects.
- Get external consultants that are TRIZ trained into the inventive problem solving phase.
- Get GE internal TRIZ experts involved in external company inventive problem solving phases.

2.2. Implementation of the Selected Solution

We decided to go for the most exciting idea: collaboration with external companies. This is especially useful in joint innovation between a company and its customer and/or supplier(s). In Bavaria there is a governmental initiative that shall promote innovations in the country: Bayern Innovativ. Within this initiative an association called quer.kraft was founded [2]. The members of this group are from different companies. A new member can only be added to the group if there is no objection from the existing members. By this it is ensured that no competitors are engaged in the same topic.

Every member of the association can suggest a topic / problem that they need to solve. Two to three times a year the group is meeting at the location of the company that puts the problem. All members work for one day on solving the challenge with TRIZ methods. The next time the problem of another company is solved. This method has been applied in the last 1.5 years 5 times in the areas of piston development, cable tights, bottle packaging, cranes and car wheels. As a result 13 patents have been generated.

The procedure of a meeting is following the rules:

The representative of the company suggesting the topic gives an introductory presentation of the company and the problem. Afterwards the team focuses on the production process of the device under evaluation. After this the group does a brainstorming on what ideas are already on the minds of the participants. This normally takes the morning time. After lunch the group splits up into subgroups and applies TRIZ tools to generate more solutions during the whole afternoon. In average we generate about 40% more ideas than with the brainstorming only.

The participation in the association has two significant advantages for companies like GE Global Research and Siemens:

- The teams use much more often TRIZ and by this stay trained and improve our innovative capabilities.
- We see how others are using the TRIZ methodology.
- We get educated on different technologies and by this broaden our capabilities especially for applying the method of “was already solved by someone else”.

Due to meeting at the company site, travel cost can get a burden and usually the number of attendees is limited to that. So only a small number of people are trained. As an alternative we tested offline collaboration. In this case within the companies TRIZ teams were set up. We had a telephone conference with other companies and the problem was stated. Then the teams worked on the subject in the morning and afternoon. In the evening we joined again for a telephone conference and presented the results. In this case it was as well interesting to see what kind of ideas were the same across the participants and where there were differences. This method was tried within the regional TRIZ associations in Europe, led by Robert Adunka and showed a fast, cost efficient international collaboration opportunity.

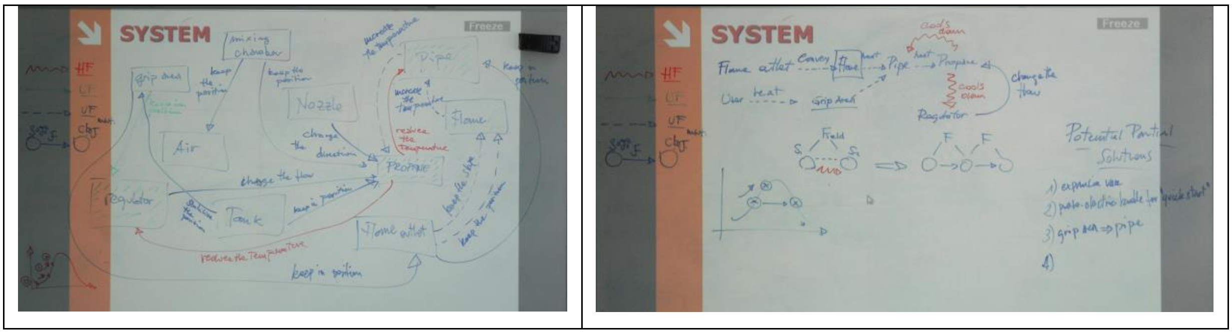
One example was a TRIZ European Workshop, were the working groups were participants from three countries. Two teams were from German companies, one from a French company and one from an Italian university, member of Apeiron (Italian TRIZ Association). Over a telephone conference the French group proposed a problem to be solved by the different groups separately. The problem to be solved was explained by a PowerPoint presentation via WebEx platform (exchange of PC screens among the participants) and the groups were given 3 hours to work on solutions on their own, free to choose whichever method they preferred. After this, the groups reconnected via a remote session and each gave a report out on the activity of the day and the list of ideas.

Fig. 3: Handheld torch

The problem was to improve the usability of a handheld torch. As main requirement ergonomics have been identified: low weight at higher or at least same operational time (Fig. 3):

German working group A went for a free brainstorming at the beginning to „clear the brain“ from biased ideas and get rid of psychological inertia by emotional attachment to the “own concept”. Those ideas are documented on a blackboard and served as preliminary storage for ideas. After that, the application of the actual TRIZ tools started. The group began with the classic function analysis methodology, going as far as component analysis, noticing at that point that for such exercise, as well as for a structured ARIZ application, 3-4 hours were not sufficient. So the Ideal Final Result was identified applying a subset of the ARIZ steps, in order to formulate contradictions as soon as possible. The group worked all together, without splitting into subgroups. The tool used to document function analysis, contradictions and principles was Innovation Navigator™.

Apeiron working group used a different TRIZ approach using functional analysis, Su-Field modelling and System Operator X application (Fig. 4).



*HOW **X** MAY SUGGEST HOW TO **ERGONOMICALLY** JOIN-DISJOIN PARTS OR USING THE TORCH?*	*HOW **X** MAY IMPROVE THE ERGONOMY?*	*HOW **X** MAY REDUCE THE IMPACT OF A POOR ERGONOMY?*
*HOW **X** MAY PROMPTLY GENERATE THE WORKING CONDITIONS FOR THE TORCH?*	*HOW **X** MAY KEEP THE TORCH WORKING?*	*HOW **X** MAY KEEP THE TORCH WORKING WITH NO AVAILABLE GAS?*
*HOW **X** MAY CREATE SENSITIVE CONDITIONS TO MAKE THE FLAME EFFECTIVE?*	*HOW **X** MAY KEEP THE CURRENT FLAME TEMPERATURE AND SHAPE?*	*HOW **X** ALLOW TO JOIN-DISJOIN PARTS WITHOUT FLAME?*

Fig. 4: TRIZ tools used by Apeiron

German working group B used the software TechOptimizer™, compiling a list of problems, and documenting ideas by means of a template for ideas including space for sketches (Fig. 5).

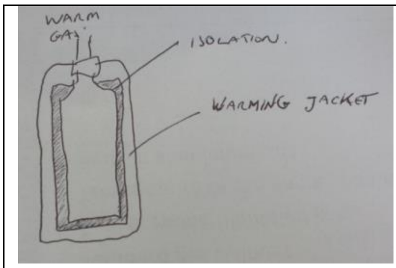
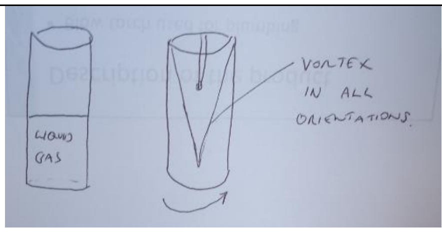
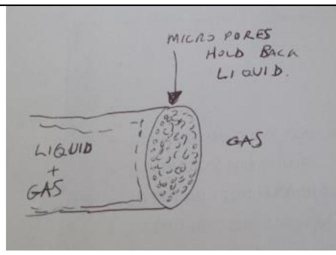
		
Local quality	Mechanical Vibrations	Local Quality

Fig. 5: TRIZ triggered ideas from the German groups A and B

The French Group focused on the definition of Main Function and Ideal Final Results.

This working day was an excellent opportunity to see a problem analysed from different point of views and solved by several TRIZ tools, reinforcing knowledge, experience and confidence in the application of TRIZ methodology. Most enriching was the number and quality of the ideas generated by very diverse approaches, shared during the report-out.

3. Learning & Duplication

With this experiment, that shows as single event no statistical relevance, we transferred a process of application over several levels.

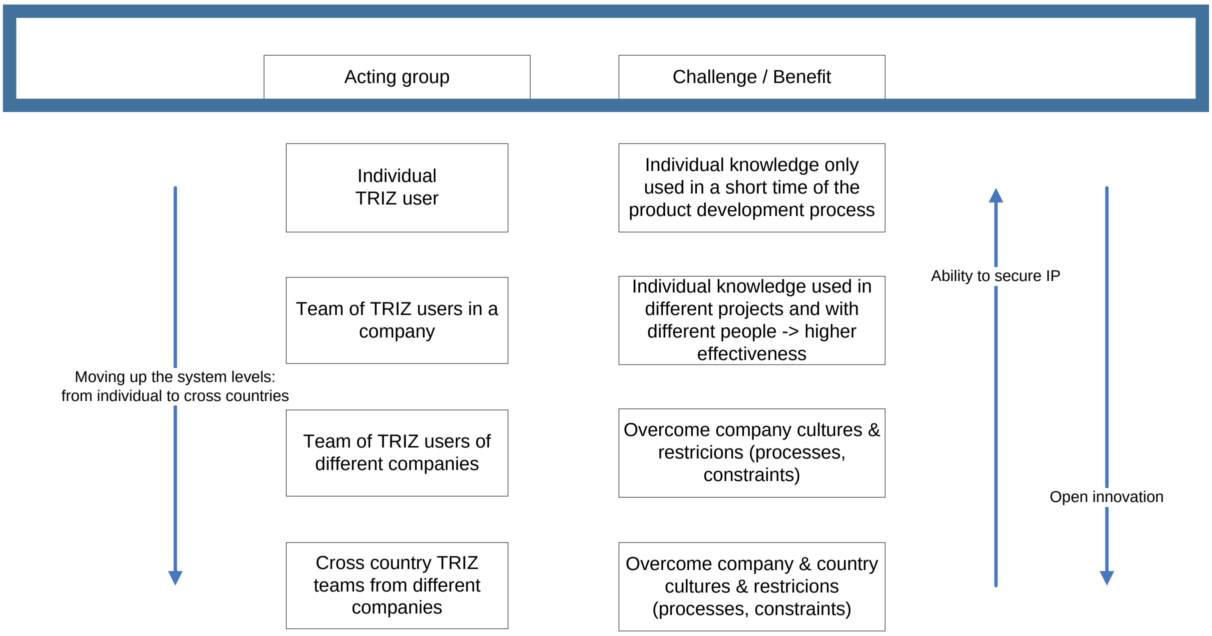


Fig. 6: Structuring for usage of TRIZ expertise

Figure 6 shows how the TRIZ expertise can be structured to improve effectiveness of trained persons. The basic idea is to use TRIZ expertise in a similar way that Altshuller rated the patent levels (from level 1 “apparent solution” resulting from personnel knowledge to level 5 “discovery” being knowledge of the world). This is especially interesting when teams from different, non-competing areas are collaborating (e.g. car industry with airplane industry). Similar developments can be found e.g. when today there is a movement from individual experts to crowdsourced knowledge (like in Wikipedia) or from node-concentrated calculation to cloud computing (also for data storage).

When using this approach one has to consider that there is a difference between Small / Medium sized Enterprises (SMEs) and big companies (> 20.000 employees). The layout shown suites well for corporate sized enterprises. They have the capacity to run such processes. SMEs often struggle with such an approach. For them outside facilitation is needed. The already mentioned “quer.kraft” offers such possibilities.

4. Summary

The evaluation showed that there is great value in creating kind of “TRIZ innovation teams” that are used to facilitate the relative short time of idea finding in an engineering project. By this experienced TRIZ applicants ensure thorough results and the TRIZ experts are continuously trained in order to keep up and improve their capabilities. This concept can be used within companies but as well across companies, especially when they are not competing on products.

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APPROACH TO KNOWLEDGE SYSTEMATIZATION

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Abstract

The article discusses the importance of solving problem of knowledge summary and systematization that is particularly topical in terms of IT-technology rapid development and rising number of interdisciplinary research and commercial projects. The article represents a short review of existing approaches to modeling of the systems evolution in TRIZ and describes authorial TRIZ evolutionary approach to knowledge systematization eliminating the disadvantages of known techniques. Authors discuss main terminology and approach application features for knowledge systematization in technical, humanitarian and mathematical fields on the example of studying the evolution of programming, numerical methods and budgeting paradigms. Trends of future researches within development of TRIZ evolutionary approach and alternative spheres of its application are considered.

Keywords: concept, budgeting, frame, forecast, numerical methods, paradigm of knowledge, programming, TRIZ-evolution.

1. Introduction

In the transition to the information society knowledge is converted into an independent value, generating a multiplier impact on other aspects of social activity. Thus, in modern society and the spheres of its existence (economy, education, etc.) knowledge creation becomes a source of competitive advantages. Notably, not only creation is advantage, but also transition, storage, systematization and use of knowledge. It also should be noted that knowledge systematization and summary are especially important.

The knowledge summary and systematization integrally with the development of logical thinking and creativity allow forming a complete picture of the world in the human mind that is especially important for professionals, who deal with studying new knowledge fields – students, postgraduates, teachers, researchers.

Unfortunately, currently, active use of methodical materials from different sources for different knowledge fields does not provide appropriate the knowledge summary and systematization. Knowledge is a "mosaic picture". Integration of knowledge is spontaneously empirical. Such a "picture" is individual for each professional, moreover, for some of them it may absent at all. "The head is filled with sketchy, incoherent knowledge looks like a pantry, where all in a mess, and where the owner will not find anything", – wrote K.D. Ushinsky [1].

So, required condition for formation of summarized knowledge is its sequential systematization, which allows applying the knowledge in various situations creatively.

Modern model of keeping knowledge in human memory assume that knowledge is stored in a type of objects and relations between them. Images and links are directly related to visions. Visions are retained images of previously perceived objects, events, facts that form main content of memory and is used for further cognitive processes.

For several years the authors offer using TRIZ objects as images for knowledge systematization [2, 3], and the TRIZ evolutionary approach for visualization and forecasting of knowledge field development. The approach assumes that the development of any knowledge field can be represented as started from some initial (basic) object to which, more and more strict requirements are imposed (new limitations are formulated) in the process of society development. Eventually, object cannot manage such requirements – there is a contradiction and often a number of contradictions arise. These contradictions develop until elimination with the usage of TRIZ tools. At the same time there is another knowledge object (further – paradigm). The process of revealing and elimination of contradictions is infinite. But what is mostly important, that in result it forms a vision of the knowledge evolution in the form of a tree consisting of knowledge paradigms, contradictions and TRIZ tools which allowed resolving these contradictions.

The authors noted that the evolution of almost any field of knowledge can be represented using a basic tool of this approach – TRIZ evolutionary model. In this case, with the growing implementation area of this model, the knowledge systematization will not be individual, but universal for all professionals, that who use the model.

The article discusses applicability of the TRIZ evolutionary model for knowledge systematization in technical, humanitarian and mathematical fields, such as programming, numerical methods and budgeting.

2. About Existing Models of Systems Evolution in TRIZ

Many TRIZ specialists, including B. Zlotin, S. Litvin, A. Lubomirsky, Yu. Murashkovsky, N. Shpakovsky and others, address the issue of different types of systems evolution. Researchers, as a rule, set different purposes. For example, B. Zlotin and A. Zusman [4, 5] purpose is construction of the General Theory of Systems Development that is applicable to learning management mechanisms of human, technologies and society evolution. S. Litvin and A. Lubomirsky [6] explored dependencies of mechanisms and instruments improving systems from the position of considered system on the S-curve. Yu. Murashkovsky [7] was engaged in the research of art and culture development lines for the purpose of art development forecasting. N. Shpakovsky [8] considered lines of systems development for the purpose of "empty" positions identification, and these positions do not necessarily have to be "inside" the line of particular system development – they may be at the ends of these lines. Such positions allow offering and realizing new technical solutions, in some cases bypassing the patents of competitors.

The techniques used by researchers are various. But, in our opinion, Zlotin-Zusman's approach associated with systemic understanding and supplementing the system approach is the most interesting. B. Zlotin and A. Zusman paid close attention to the identification of patterns, analyzing the history of real systems, analogies and coincidences in evolution, "beautiful" inventions, resources, completed projects, personal experience, "historical puzzles", etc.

The above listed practices influenced the current research. However, it became impossible to completely use any of evolution models known in TRIZ for the knowledge systematization – from basic to relevant object knowledge object. Therefore, for summary and systematization it is offered to use the TRIZ evolutionary approach.

3. Main Definitions

The TRIZ evolutionary approach is based on a number of concepts borrowed from various fields of scientific knowledge, such as philosophy and methodology of science, system analysis and knowledge engineering. Such concepts are "paradigm", "concept" and "frame".

The term "**paradigm**" is used in the interpretation of T. Kuhn, according to which a paradigm is a set of conceptual and technological attitudes ensuring the existence and development of a particular area of scientific knowledge. T. Kuhn wrote: "By choosing it, I mean to suggest that some accepted examples of actual scientific practice – examples, which include law, theory, application, and instrumentation together – provide models from which spring particular coherent traditions of scientific research"; "Attempting to discover the source of that difference led me to recognize the role in scientific research of what I have since called "paradigms." These I take to be universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners" [9].

The **concept** in the TRIZ evolutionary approach is understood as a contradiction or set of contradictions and TRIZ tools of their elimination that lead to the emergence of a new paradigm. Accordingly, concept and paradigm are different terms. The concept is a driving force for emergence and change of paradigms.

As for the **frame**, it is a structure that contains description of object, process, event, phenomenon or situation (further – system) in the form of some pattern, while the described system exists within a certain paradigm of scientific knowledge (figure 1, item 1) and is its carrier (figure 1, item 5).

The systems existing within a certain paradigm continuously evolve, meeting requirements of environment. Depending on requirements society imposes for a system at the concrete particular stage of its development, it is possible to allocate key parameters which are valuable for a particular user of a system or other person interested in its development. In fact, such parameters may be "main parameters" (see Main Parameters of Value [10] from GEN3's methodology), designated as MP in figure 1 (item 2) and further in the text.

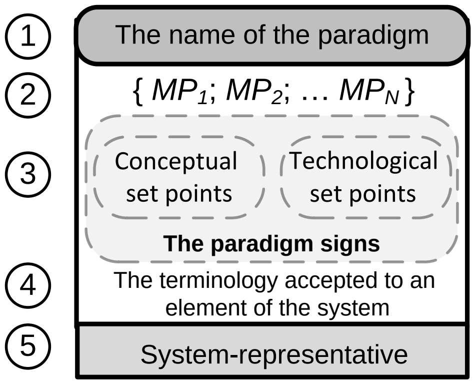

Fig. 1. The visualized structure of the frame

In figure 1 the main conceptual and technological set points forming the paradigm within which the system exists and evolves, directly associated with it, are displayed in the item 3. Terminology applicable to an element – basic, indivisible structural or functional unit, the division limit of the system (in the context of the systematization and summary problem and also of the knowledge field peculiarities), – is formulated in item 4.

In the last, 5th item, an example-representative of the systems existing in the present paradigm (e.g., language, method, technique, make or model, etc.) is reviewed.

4. Theory of Programming as a Knowledge Field

Let's consider the applicability of the TRIZ evolutionary approach to research of application-oriented technical knowledge field – to programming.

It is assumed that evolution of programming as an independent theory and element of scientific knowledge started by the emergence of: 1) the theory of functions – the mathematical formalization supporting languages of the functional programming, offered by Moses Schonfinkel in 1924; 2) the system of machine instructions coding by means of special characters offered by J. Mouchli in the middle of 1949.

During the existence of programming as independent field of knowledge range of problems which can be resolved by software and forms for such resolutions representation have cardinally changed. Working methods have also changed. Technological achievements in hardware, operating systems and programming languages allowed creating the development environment [11].

The current research subject, evolution of which will be reconstructed and systematized using the TRIZ evolutionary approach, is computer programming languages especially requiring systematization in the light of the IT-technology rapid development in modern society.

Software developers periodically meet the issue of choosing language for their software implementation. The language features of one language can be reproduced in other languages, which don't support them directly. Consequently, many language features can be replicated in different languages. In our opinion, this is caused by the evolution of programming as an independent knowledge field [2].

Obviously, each new paradigm will have the signs of group-predecessor to some extent. Thus, learning different programming languages is reduced to learning programming languages concepts, and the choice of the programming language is reduced to determination of the best set of MP for some language, suitable for the solution of a specific task. It should be also noted, that each new resolution of a contradiction in an existing paradigm changes the target set of this paradigm MP.

5. TRIZ evolution of Programming Paradigms

Let's consider main stages of programming languages paradigms evolution via examples. We defined the concept "*programming*" as a process of describing programming idea using programming language, which is understandable for receiver and transmitter. Therefore, "*programming language*" is a special case of the term "language", which means a tool of communication between transmitter and receiver to implement program ideas [2].

As it was previously mentioned, the first full-fledged programming paradigm which meets the terminology (item 3) is *native programming*. It is a set of instruction in machine code, which is interpreted for a particular microprocessor (figure 2).

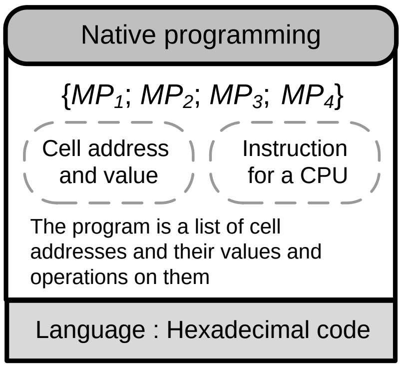

Fig. 2. Frame of the "Native programming" paradigm: MP_1 – complexity of tasks (problem);

MP_2 – size of a source code (machine operations); MP_3 – structure of a CPU;

MP_4 – programming time.

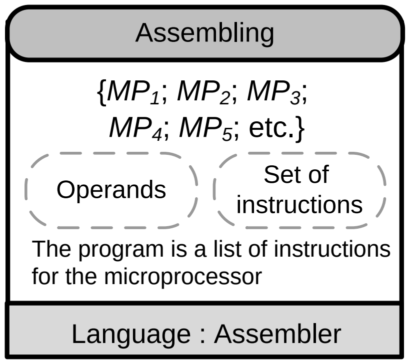

Fig. 3. Frame of "Assembling" paradigm:

MP_1 – complexity of tasks (problem);

MP_2 – size of a source code; MP_3 – structure of a CPU; MP_4 – programming time; MP_5 – complexity of a source code; etc.

The following contradictions are revealed in the process of this paradigm development. *Contradiction 1*: with increasing tasks complexity size of a source code (machine operations) UNACCEPTABLY increases. *Contradiction 2*: with increasing tasks complexity a CPU structure becomes UNACCEPTABLY complicated. *Contradiction 3*: with increasing tasks complexity time for programming UNACCEPTABLY increases. To eliminate the revealed contradictions inventive principles [12] of (26) "Copying" and (5) "Merging" are used.

Let's consider specific resolutions that eliminate identified contradictions. *Resolution 1*: using the principle of Copying, the term "address cell" and its value is replaced by the term "operand". *Resolution 2*: using the principle of Merging, similar machine instructions and mnemonic commands are combined. As a result of contradictions elimination, a new resource is developed: ability to convert machine instructions to the mnemonic code.

Assembling is the next paradigm, in which compilation of a source programming code, written in assembly language, is performed into machine language code. Addressing to a processor is performed by the usage of mnemonic commands that complies with machine instructions of a computer system (see figure 3). Usage of mnemonic code introduced by the "resolution 2" of contradictions considered earlier reduces time for programming and size of a source code without complicating a CPU structure.

In turn, the development of "Assembling" paradigm also generates a number of contradictions. *Contradiction 1*: transferring program to another platform UNACCEPTABLY increases the number of incompatible parts of program commands and CPU. *Contradiction 2*: increasing tasks complexity UNACCEPTABLY increases size of a source code. *Contradiction 3*: increasing tasks complexity UNACCEPTABLY increases time for programming. *Contradiction 4*: increasing number of implemented mathematical functions UNACCEPTABLY breaks computation logic. *Contradiction 5*: increasing complexity of implemented mathematical functions UNACCEPTABLY breaks computation logic. *Contradiction 6*: proving mathematical theorems UNACCEPTABLY breaks computation logic.

To eliminate revealed contradictions inventive principles of (5) "Merging", (2) "Taking out" and (10) "Preliminary Action" [12] were used. As a result the *imperative paradigm* appears, replacing the paradigm of assembling.

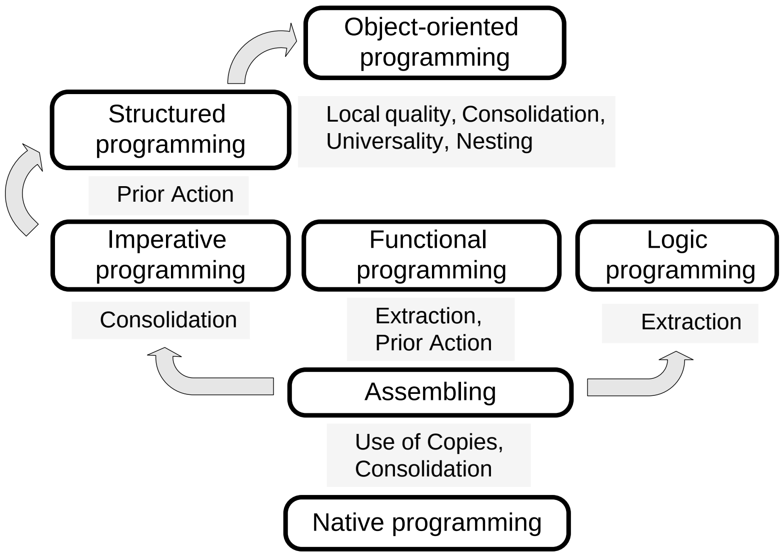

Fig. 4. The fragment of the TRIZ-evolutionary map of programming paradigms

Thus, at each stage of a new paradigm emergence there is a conflict – there are contradictions between requirements of a super-system (for example, communities of the programmers solving application-oriented problems) and capabilities of a system (the functional limitations of programming languages which are caused by an existing paradigm). Identified contradictions are also resolved by TRIZ tools therefore ideality of paradigms increases, and the use of language belonging to an evolving paradigm becomes more productive and reliable. Read more about evolution of paradigms in [2] in the context of solving the task of factorial function evaluation.

Combining paradigms and concepts in term of inventive principles application to elimination of technical contradictions, we receive the **TRIZ evolutionary map** (figure 4). Such a map is a base graphic model in terms of the TRIZ evolutionary approach.

The use of TRIZ evolutionary map allows increasing learning efficiency through a systematic representation of knowledge about the evolution of paradigms in some knowledge field. The digestion of the concept allows summarizing the fragmentary knowledge about field knowledge field and understanding the basic principles of paradigms change within it. Paradigms representation in the form of frames, in turn, allows systematizing knowledge and to formulate a technique of its teaching or organized extraction from formed visions.

6. Modeling of Alternative Concepts

The initial definition of "concept" (section 2) includes contradictions between general requirements of a super-system dictated by an initial goal of system creation and level of current scientific and technical progress, capabilities of the researched system and also TRIZ tools for resolving such contradictions. However, such a definition does not consider which group being a part of a super-system formulates requirements. Besides, contradictions can arise between requirements of different groups. Even groups can be defined in different ways – depending on the context of a systematization task being solved.

For example, in case of solving summary or systematization tasks in the educational purposes it is enough to consider the traditional method of contradictions formulation used in the TRIZ evolutionary approach (item 4). At the same time, in case of the solving systematization task in area particular knowledge field in order to forecast the necessity of a new system creation or to manage the evolution of some group of systems, it is important to study requirements imposed to a system as user, developer and owner

In this way, the technique of formulating contradictions of the TRIZ evolutionary approach can be expanded to be used for forecast purpose relating to artificial systems development in various knowledge fields. Let's consider some ways to improve the author's technique.

Methods of grouping contradictions by types and techniques on performing analysis of useful properties and key consumer values of a system from a viewpoint of its developer or a user are given in [13–15]. So the method of contradictions detection through an assessment of a current value of quantitative and qualitative parameters of a system in relation with customer requirements and market tendencies is offered in researches [13–14]. At the same time, the formulated contradictions are divided into three types: between user requirements, between user and business requirements, between business requirements.

Another important moment that should be considered in case of formulating contradictions which are the basis of the concept of knowledge paradigms change during their evolution is considered in [15]. Earlier the TRIZ evolutionary approach considered only revealing contradictions in terms of a super-system requirements, that are imposed for a system (as in [15], it means correspondence of a system features to the environmental needs). But it is also necessary to consider the correspondence between requirements of a system and super-system capabilities, and potential existence of system features harmful to an environment.

Thus, for a particular knowledge field there can be several TRIZ evolutionary maps, depending on the concepts underlying the changes of knowledge paradigms. In turn, the concepts are different because of differences between approaches to contradiction formulation. Contradictions can be revealed considering:

1. General requirements of a super-system (environment, observer, etc.) and the capability of a system (for educational or research purposes);
2. Specific requirements of a super-system by observers groups (for engineering and commercial purposes);
3. Specific requirements of a super-system and capability of a system (for research, engineering and commercial purposes);
4. Compliance of system requirements and capabilities with a super-system (for research and engineering purposes);
5. Assessment of potential existence of system features harmful for a super-system (for research, engineering and commercial purposes).

It should be also noted that the quantity of contradictions which can be selected at stages of paradigms change is not limited in any way. But if there are more than tree of such it is advisable to conduct additional analysis ranking contradictions in order of their importance. It allows determining the priority of contradictions elimination in the context of a formulated systematization task. Ranking can be performed using special instruments that are based on expert assessments (for example, Ishikawa diagram).

7. Application of the TRIZ evolutionary Approach in Nontechnical Fields

The TRIZ evolutionary approach can be successfully applied to systematization of knowledge about objects and processes not only in technical, but also in any other spheres. As an example let's consider mathematical knowledge field – *numerical methods*. These are methods of approximate solution of typical mathematical problem (tasks) reduced to a finite number of elementary operations on numbers.

Existing systematizations of numerical methods are very manifold; this fact complicates choosing a suitable method. The classification analysis of numerical methods showed that numerical methods evolve both during development of description models of real physical objects and during development of problem resolving techniques presented by corresponding objects [3]. The evolution process of models is associated with the increase of mathematical models adequacy to their real physical prototype. The evolution process of numerical methods is concerned with the increase of ideality of existing models realization. Thus the ideality criteria consist of accuracy, convergence, number of arithmetic operations, etc.

For example, let's consider in detail the line of development of real physical objects description models, i.e. we will consider the development of mathematical models which describe objects of the real world more and more adequately. The first models were *linear algebraic equations systems*. In the development of such systems there was a contradiction: increase of closeness of agreement of linear equation systems solution to test data led to

UNACCEPTABLE increase of calculations volume. To eliminate this contradiction the principle of (17) “Another Dimension” [12] was used. In this case “another dimension” means transition to the category of non-linear functions (equations).

Transition to non-linear equations, as a result of contradictions resolution, allowed describing functioning of technical object more or less adequately but only in one field sub-system. For example, welding process had been described only in electrical sub-system. But in any real technical object there are processes referring to different sub-systems. In the welding process, electrical sub-system is only initial one, then heat sub-system appears, then deformation, hydraulic and other sub-systems follow. While resolving non-linear equations of different sub-systems are not connected with each other, there are significant mistakes. Thus, there is a contradiction, which can be eliminated by the (5) “Consolidation” [12] principle. Such a resolution allows technical object describing by the system of non-linear equations, etc.

So by resolving contradictions arising during the evolution of numerical methods paradigms, the line of evolution of mathematical models of describing real objects is formed. The lines of evolution for separate methods of solving problems for each group of real objects are similarly formed [3]. The examples of paradigms frames for descriptive models and methods of solving problems are presented in figures 5-6.

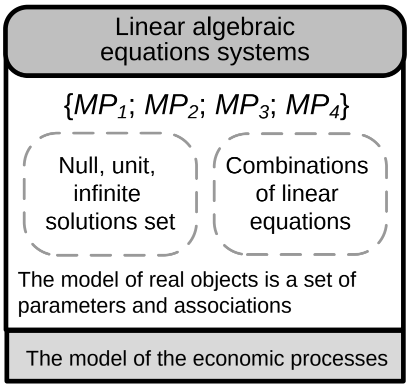

Fig. 5. The frame of paradigm “Linear algebraic equations systems” within the line of description models evolution: MP_1 – dimension of a model; MP_2 – adequacy of a model; MP_3 – controllability of a model; MP_4 – forecast value of a model.

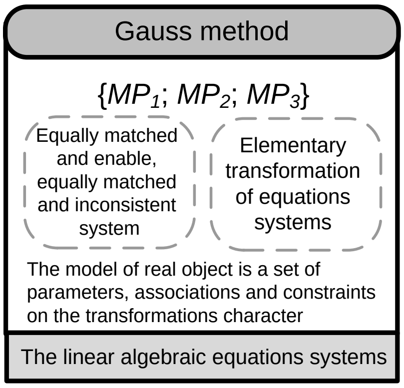

Fig. 6. The frame of Gauss method within the line of “Linear algebraic equations systems” evolution: MP_1 – degree of convergence of the method (the number of arithmetic operations); MP_2 – structure and the order of a matrix; MP_3 – calculation accuracy.

The fragment of the TRIZ evolutionary map of numerical methods is compiled from the research of all main lines of methods development (figure 7). The complete map is available in [3].

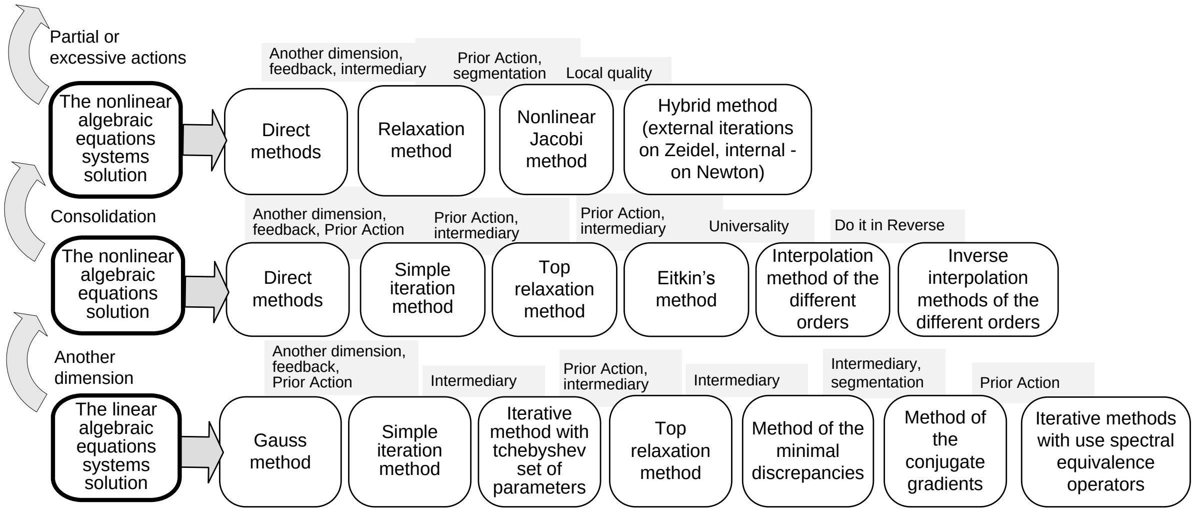

Fig. 7. Fragment of the TRIZ evolutionary map of numerical methods paradigms

Another example of the TRIZ evolutionary approach application in nontechnical knowledge field can be *budgeting*. It is a process of the organization management, which includes coordinated planning and control of financial and economic state with distribution of responsibility for the results of operation. Let's consider some transitions from one paradigm of budgeting to another in more detail (figures 8–9).

Old cameral accounting became the initial paradigm that was the basis for the emergence and development of the system of budgeting in its current meaning. It should be noted that to begin reviewing with paradigms of unigraphic or biographic accounting is more expedient in the case of researching "accounting" systems, but not "budgeting".

In the development of the old cameral paradigm some contradictions are identified. *Contradiction 1*: with increasing time for operation of the fixed assets the error of estimation of the fixed assets cost UNACCEPTABLY increases. *Contradiction 2*: with decreasing time for financial planning quality of the financial planning UNACCEPTABLY decreases. These contradictions are resolved using principles [12] of (10) "Prior Action", (1) "Segmentation", (11) "Early Cushioning", (5) "Consolidation", then there is a transition to a new paradigm of budgeting, which is *new cameral accounting*.

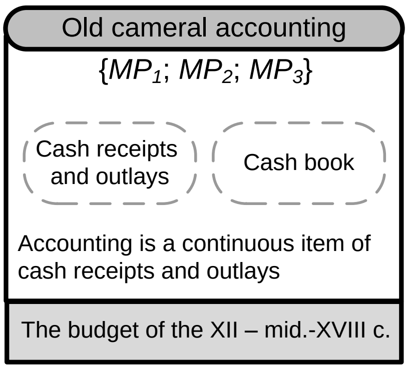

Fig. 8. The frame of paradigm "Old cameral accounting": MP_1 – time for operation of the fixed assets; MP_2 – accuracy of fixed assets cost; MP_3 – time for financial planning.

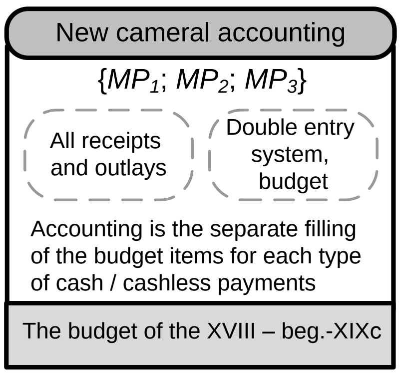

Fig. 9. The frame of paradigm "New cameral accounting": MP_1 – number of accounted transactions; MP_2 – number of errors; MP_3 – types of calculations.

Creation of a new paradigm leads to new contradictions. *Contradiction 1*: with increasing number of accounted transactions that are not included in the budget quality of work UNACCEPTABLY decreases. *Contradiction 2*: with increasing number of accounted transactions the number of budget preparations errors UNACCEPTABLY increases. The revealed contradictions are eliminated using principles [12] of (11) “Early Cushioning”, (3) “Local Quality”, (23) “Feedback”, (25) “Self-service”. It leads to the creation of a new paradigm – *constant accounting*; and so on.

The change of budgeting paradigms according to the TRIZ evolutionary approach, in our opinion, s performed as follows (figure 10). The current stage of budgeting development is the *systems without a budget*, which represent a package of measures on the management of organizations without prior planning and adoption of budgets in order to optimize the allocation of resources. As well as for any other paradigm, it is clear that systems without a budget have a number of contradictions, which can be eliminated using TRIZ tools.

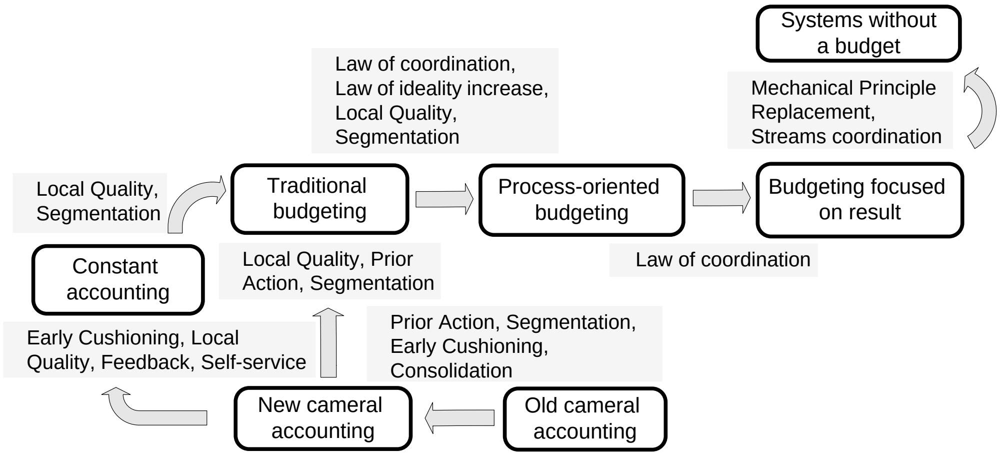

Fig. 10. TRIZ evolutionary map of budgeting paradigm

During the life line of a paradigm, it is difficult to forecast which resolution of a contradiction will lead to significant change of conceptual or technological set points (i.e. to the creation of a new paradigm). However, after summarizing and systematizing knowledge about previous paradigms and highlighting main development trends of an existing paradigm it is possible to use the TRIZ evolutionary approach in its active phase – to forecast the development of a knowledge field, as to the formulation of set points for new paradigms and creation of new systems implementations (which are representatives of frames, fig. 1).

8. Conclusions

The proposed approach allows summarizing and systematizing the vision of a paradigm change in fundamental and applied practical knowledge fields in the past, present and future for educational and research, and also engineering and commercial purposes.

The technique of contradictions formulation within the TRIZ evolutionary approach can be expanded and used not only for solving the problem of information systematization, but also for forecasting the development of systems in a variety of knowledge fields.

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TRIZ*fest* 2015

CREATIVITY AND INNOVATION PROCESS

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Abstract

People started to innovate at the dawn of civilization. When man picked a rock for a purpose, say, of breaking a nut, he invented a tool. Nobody recorded the very first invention. Yet, today we know that the biggest difference between humankind and the rest of the biological world is our ability to engage in a directed thought process. Therefore, we can solve various problems much faster than any other species. The problem solving skills are the foundation for developing creative thinking skills, which are a must for commencing and sustaining any innovation process.

In this paper, I discuss the importance of teaching problem solving for developing creative thinking skills, which is a prerequisite for any form of innovation process.

Keywords: TRIZ, problem solving methodologies, creativity, innovation, open problems

1. INTRODUCTION

Innovation is, undeniably, a buzz word of the young 21st century and for a good reason. Renowned physicist Leo Szilard proposed a simple, yet elegant image: Let's represent all human knowledge as a ball. Then the space outside of the ball is unknown territory. The surface of the ball symbolizes the border with the unknown. But the larger the amount of knowledge, the greater is the area of contact with the unknown. And each point of the interface with the unknown is a problem that needs solving in order to acquire new knowledge. Or for an enterprise, it means solving a problem in order to improve profitability. Thus, the need for innovation may stem from a number of different situations.

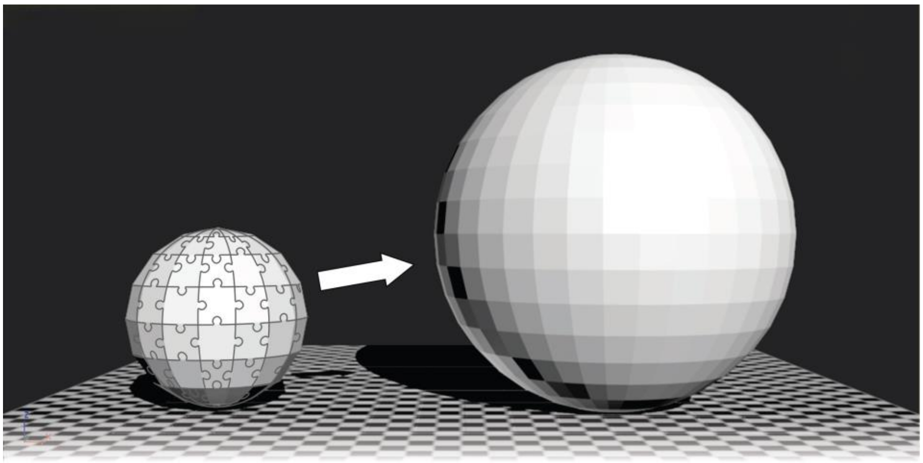

Fig. 1 As Knowledge Grows, Unknown Grows Along

Seemingly insignificant tweaking of a product, process or service may result in solid foundation for process of innovation. One must be creative to invent something new. However, to find a way to improve on an existing product, process or service requires as good, or better, creative thinking skills. Unfortunately, creative thinking skills are not taught in grade school or university.

Consultants, who are involved in training of various problem solving methodologies, are very aware of the fact that adults can't learn. This is another skill nobody teaches on any level of the educational process.

2. A FEW MORE WORDS ABOUT INNOVATION PROCESS

Before a problem is solved, somebody must be able to see and to define this problem. This is another trait of a creative individual – an ability to see a problem, a need or a potential for an improvement. Most of people see life as a chain of events; a creative person sees life as a series of challenges/problem. Once the problems are noted/defined, a creative individual may improve their quality of life by solving these problems.

In a nut shell, innovation process in a business setting may be triggered by one of the following needs:

1. Improvement of a product;
2. Improvement of a manufacturing process;
3. Cost reduction.

While every type of innovation process addresses different aspects of a business enterprise, the process of innovation, by and large, remains the same:

1. Situation analysis and problem formulation
2. Idea generation
3. Synthesis of the concepts, based on selected ideas
4. Design, based on selected concept

5. Implementation

With this said, it is obvious that creativity is a must for success in every kind of the innovation process.

Statistically, the appearance of the word "INNOVATION" in English language books more than doubled in the last decade. [1] Furthermore, when this author Googled word "Innovation" it produced 338 million hits, more than twice as many as hits for Angelina Jolie, Albert Einstein or Miley Cyrus. Many companies, big and small, use this word to define their approach to provide a better customer experience with their products or service.

Although innovation is a topic on the minds of many people, when business people are asked to define innovation they often struggle to give a precise definition. Innovation is a term that is often defined loosely and in many different ways. It will be helpful at this point to define exactly what we mean by innovation. The American Heritage Dictionary defines innovation as "To begin or introduce something new". There is an important difference between invention and innovation. Jan Fagerberg at the University of Oslo makes the following distinction. "Invention is the first occurrence of an idea for a new product or process. Innovation, by contrast, is the first attempt to carry the invention into practice." No innovation exists where there is no practical application of an idea.

3. ASSESSMENTS OF VARIOUS TYPES OF INNOVATION

While Business Model Innovation provides the best return on investment, it is important to distinguish between Products/Services/Markets innovation and Operations, internal business and manufacturing process, innovation. The former is risky; it heavily depends on market acceptance and may suffer from insufficient resources. On the other hand, the latter is firmly under control of an enterprise and only requires an internal consensus. It has virtually unlimited access to all available resources.

The IBM study (2) conveys the fact that companies, which proportionally invest twice as many resources for Business Model Innovation, enjoy nearly 5 times the profits.

Yet, the management is often reluctant to sign off on innovation project. In my paper at TRIZ*fest*-2014 (3) I expanded on various ways of convincing the management to invest in innovation projects. However, it is always a struggle, especially in a large organization, to justify a budget for innovation project.

The cartoon below underscores management's reluctance to even look at a potential profit producing innovation.

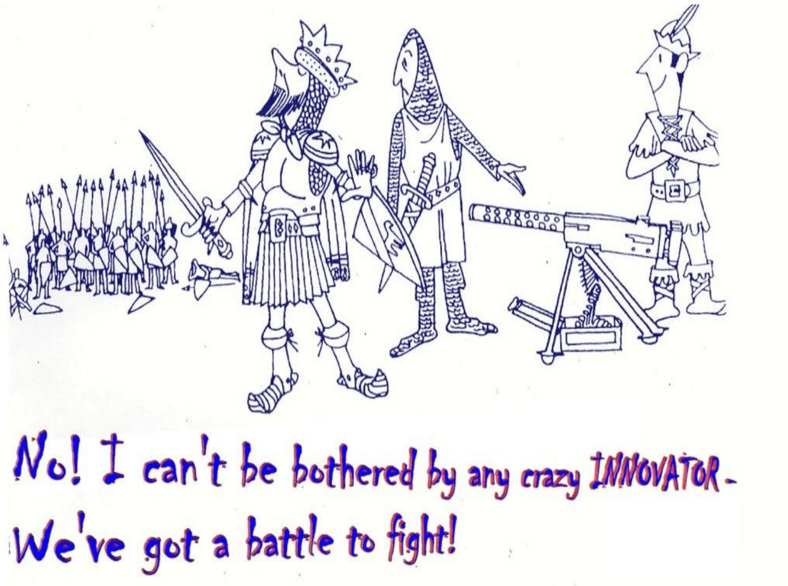

Fig. 2 Misunderstanding useful resources

And it is hard to blame managers for such behavior. In the current business climate, where a manager is moved around company's departments every 3-4 years, a long term project with uncertain results is hard to sell. What if it fails – a manager is guaranteed a blemish on his/her resume.

4 THE ROLE OF CREATIVITY

It is obvious that creativity is one of the most important features of a present day associate of most enterprises. In fact, today, most of businesses evaluate a new graduate of a technical or business curriculum on three criteria: the knowledge of the subject matter; an ability to function in a team; and problem solving skills. The latter one becomes more important in today's dynamic world. Take for example the situation with the present day oil prices. For a consumer, a less than $50/barrel is great. We don't have to pay as much at the pump. For an oil producer it is not as good. In the United States, which lately emerged as one of the world's major oil producers, the cost of producing a barrel of oil is over $50/barrel? So, what is the outlook? According to the experts oil companies will sharply reduce drilling. Seldom anyone predicts a massive innovation effort in order to reduce the cost of oil production. This author participated in a cost reduction effort with an oil company in 1998. Representatives of 4 major oil companies, in a Value Engineering session, were trying to reduce the cost of an offshore oil producing system. As designed, this system was estimated to cost $1.3 billion. The top capital expense for a feasible project stood at $1 billion. The process consisted of mining the oil/water mixture, separating oil from water, pumping it into a tanker, holding oil in the tanker for 3-4 days, pumping oil to a refinery. Even though it was already fifth session, nobody saw a time resource, which could eliminate the oil/water separation system with its cost of $225 million. After separation, oil was sitting in a tanker for a minimum of 3 days. The unassisted, natural, oil/water separation takes 8-10 hours. Thus, there is a great potential for elimination of oil/water separation system, along with its cost of $225million.

5. TEACHING CREATIVITY

For more than 200 hundred years the present educational system is based on rote memorization of material and testing of students' memory. This method was, say, sufficient for educating factory workers and soldiers. This system was also great for developing obedient citizens for any country, employing this system. At the same time, our society was producing enough geniuses for supporting sufficient rate of progress.

Late 19th, early 20th century Théodule-Armand Ribot, a French psychologist, suggested, based on numerous test, that children reach the peak of creativity by the time they become 14 years old. After that age our creativity is reduced by a little bit every year. Today, creativity peaks at about 12 years.

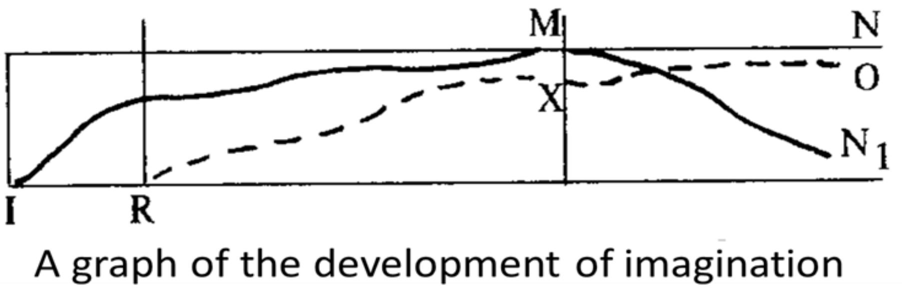

Fig. 3

In our opinion, the existing educational system is the culprit here. School programs suppress individuality, initiative, and therefore creativity. Every child is born creative. The way we stuff them with knowledge obliterates natural curiosity and the desire to experiment with new things. The system forces students on every level to memorize a bunch of information, and then it tests their memory.

At the end of the 19th century, with the advent of information technology, the pace of creating new knowledge started to increase exponentially. The volume of the unknown was growing as fast. The pace of change picked up considerably. 100 years ago there was maybe one change per month, today, the change is constant. Thus, there were not enough natural born geniuses. By the mid 1920s, people started to look for various ways to educate creativity. Most of efforts were directed at the attempts to understand and harness psychological nature of creative thinking process. Understandably, not much good came out of these efforts. Individual psychology is individual psychology, it can't be replicated.

About 25 years ago some TRIZ practitioners, Zlotin, Ivanov, Guin, to name a few, started developing what we call today TRIZ-pedagogic. This methodology is based on TRIZ and just about every other problem solving and idea generation methodology. The situation analyses and problem formulation are as important segments of TRIZ-pedagogic as the eventual problem solving.

We believe that one can't learn how to swim by reading a book. Conversely, one must think in order to learn how to think. In our everyday life, we only think when we are faced with a problem. Yet, this is hardly an everyday occurrence. Bernard Show, who was considered one of the smartest people of his time, was once asked how is it that he is so smart. His answer was quite telling – I am smart because I think at least once a week.

To learn how to think is only possible by solving open problems. Closed problems teach how to use predetermined problem solving process and associated formulas. In real life, we face no closed problems. Real life problems are always open problems, solving these problems requires well developed creative and analytical thinking skills. Some people are born with those skills, most need to learn. The existing educational system must be changed in order to provide young generation with the skills, required for life in harmony with the dynamic world we live in today.

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DEVELOPMENT OF SYMBIOTIC SYSTEMS AND PRODUCTS

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Abstract

Symbiosis (from Greek σύν "together" and βίωσις "living")[1] is defined in biology as close and often long-term interaction between two or more different biological species. In Theory of Inventive Problem Solving, symbiotic systems were initially described by Boris Zlotin and Alla Zusman as a way to create bi- and poly-systems [2].

This article will consider role of symbiotic systems for creation of modern consumer products and provide recommendations for development of these types of the products.

Keywords: Hybridization, symbiotic systems, how to create symbiotic products

1. Introduction

According to Encyclopedia Britannica, symbiosis is any of several living arrangements between members of two different species, including mutualism, commensalism, and parasitism. Both positive (beneficial) and negative (unfavorable to harmful) associations are therefore included, and the members are called symbionts [3]. Goal of this article is to consider positive association between technical (engineering) systems.

Boris Zlotin and Alla Zusman have proposed to use symbiosis in framework of development of ideas of creation new bi- and poly-systems. They have recommended to find a second system that possesses resources (e.g., information, energy, a substance, space) that your system needs, and integrate the two systems. This may facilitate a better overall implementation of your system's primary and auxiliary functions [2]. Hybridization in technology was initially described by Valeriy Prushinskiy, Vladimir Gerasimov and Gafur Zainiev in their book “HYBRIDIZATION: The New Warfare In The Battle For The Market” [4]. Also, basic hybridization schemes were developed by author in his book “Everyone can invent” [5].

In this article, author utilized modern crowdfunding websites for study of modern trends in consumer products and technologies with follow-up selection of the relevant examples for development of symbiotic products. Numerous examples were studied, since the products, funded through these sites illustrate proven demand of possible buyers that are willing, able and have a financial means to purchase proposed new products. Since the audience is supporting these products, they provide novel growing trend in development of consumer products.

2. Selected Examples of Symbiotic Products

Symbiosis is distinct trend in consumer electronics, that's why tens of examples were collected in process of this study and thoroughly investigated in order to provide recommendations for development of such systems and products. Three of these examples are briefly described below.

Example 1 - PhoneDrone

PhoneDrone is a concept of smart phone that can be inserted into the drone, so that it will provide camera and control organs for unmanned aerial vehicle (fig. 1).

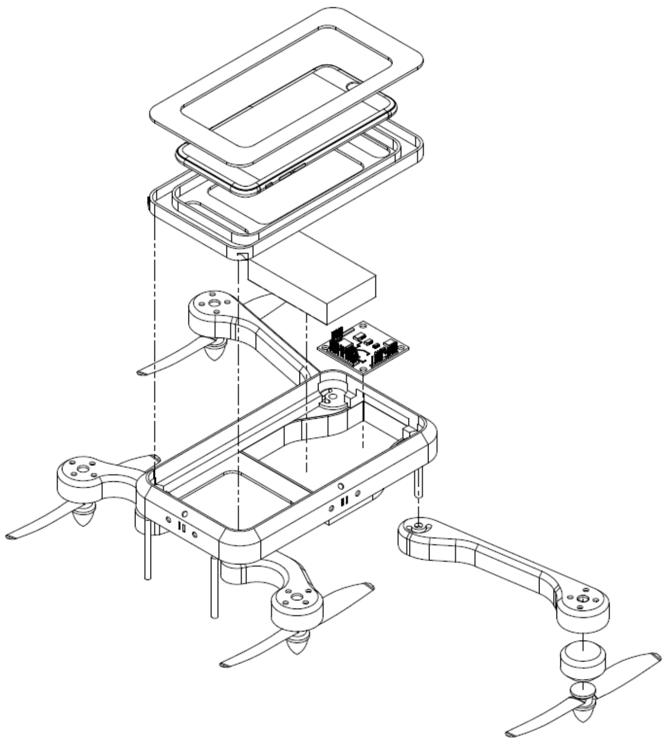

Fig. 1. PhoneDrone Concept [6]

As we can see, in this concept, instead of development of sophisticated electronics, developers have decided to use resources of the ready available smart phones as means of control organs and smart phone's camera in order to take images and videos from the flying drone. They focused on cooperation with leading system, which is manufactured and sold in hundreds of millions every year. This way, potential users will be familiar with convenient interface of the smart phone and use of similar interface for drone's control and it will reduce entry barrier for new concept.

Using the smart phone as symbiont technological system enables developers proposing their new products to huge audience of smart phone users. In addition to this own communication and control sub-system is not required for the drone in framework of this concept. Now, instead of development hardware for these sub-systems, the inventors have developed only smart phone application (software) carrying out these functions.

Example 2 - Nuimo

Nuimo is wireless controller for smart household devices. This device is designed in framework of developing Internet of Things (IoT) trend. You can open/close smart locks, switch on your music players and light. Unlike the touch screen, Nuimo has a number of touch based inputs that feel familiar and suit your needs. It incorporates capacitive touch, gesture recognition and a 360 degree analog ring that gives you precise control over everything from the volume of your music to switching off your lights.

Since Nuimo can connect wirelessly with any smart home device, it exists in symbiosis with numerous household devices, providing you the function of universal controller and allowing you to control your music, lights, locks and many other devices on-the-go, without physical contact with these devices.

Fig. 2. Nuimo mobile universal IoT controller [7]

Example 3 – Prynt: printer-case for smart phone

Prynt is device, which works symbiotically with smart phone. In fact, it is printer, designed in shape of smart phone case. This case turns your smart phone into a Polaroid-style camera that prints photos. Additionally, those photos turn into augmented reality videos when viewed on the phone's screen. One can plug it in own smart phone, snap a photo or choose one from your favorite social network, and print it out in thirty seconds. This concept is so simple, that it have meet overwhelming support and 9,023 people pledged $1,576,011 to help bring this project to life.

Fig. 3. Prynt: the first instant camera case for smart phone [8]

Traditionally, initial concept of the engineering system or product has to include all subsystems, required for survival of new system. However, as we can see in above described examples, in modern innovative practice, there is a trend to find symbiotic system that provides opportunity to simplify initial design. Also, during the selection of symbiont system, one have to select the systems that is mass produced, because this will increase a chance of survival for new system/product by providing opportunity to address unmet needs of substantial market.

Currently, following global manufacturing trends have been observed [9]:

1. Product variety and complexity continue to increase.
2. Product life cycles are becoming shorter.
3. Customers are consistently demanding high-quality, low-cost products and on-time delivery...

As has been described in above mentioned examples, development of symbiotic systems provides opportunity to follow these global manufacturing trends trends and provide substantial competitive advantage, since it simplifies design, manufacturing and address already existing customers of selected “symbiont” device.

3. Conclusion and future trends

Based on observations of modern crowd funding websites, trend of development symbiotic consumer devices will remain “hot” for development of new concepts. Following steps can be recommended for development of initial concepts of symbiotic consumer products:

- Define primary function of future engineering system and its market niche
- Describe initial concept of future engineering system and select components, carrying out main function(s)
- Think of “leading” product(s) in defined niche and try to think of this (these) engineering system as “symbiont” one
- For selected components, think how “leading” product can provide at least some of their functions
- Describe portrait of new product that will operate symbiotically with selected “leading” product or engineering system

Symbiotic relationships have to be beneficial for both engineering systems. In order to find successful new concepts of symbiotic technological systems, one should think about unmet needs of the selected “leading” system, because this approach can provide a basis for generation of promising solutions and better innovative concepts. Also, as a rule, good concept of symbiotic product describe system, where some functions are provided by symbiont system, that’s why these sub-systems are not needed and can be excluded from initial concept of new product.

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EVOLUTION OF ELECTRIC VEHICLES - A TRIZ BASED APPROACH

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Abstract

The purpose of this paper is to study the current status of electric vehicle (EV) industry using TRIZ based S-curve methodology. The energy density of electric vehicle has been considered as the Main Parameter of Value (MPV) since it directly affects the performance of the engine as well as determines customer purchasing decision. An increase in the capacity of energy density of batteries was observed over a period of time. This was correlated with patent trend & global sales numbers and inferred that EV industry is in the 2nd stage of the S-curve. The indicators from the EV industry that are typical for 2nd stage of the evolutionary curve are discussed. Based on the indicators, TRIZ based recommendations for growth of an engineering system in the 2nd stage are provided.

Keywords: Electric vehicle, TRIZ, S-Curve, Main Parameter of Value, Energy density.

1. Introduction

In the recent years, electric vehicles (EV) have emerged as the preferred alternative to transport systems that run on fossil fuels, thanks to the environmental benefits of zero tailpipe emissions and the vehicles' ability to take power directly from the power grid [1]. In spite of this major benefit, EV industry still faces stiff challenges to create a dent in the conventional automobile market. In this paper, a TRIZ based S-curve analysis has been employed to understand the current evolutionary stage of EV industry. The energy density of electric vehicles has been considered as the Main Parameter of Value (MPV) and is compared with the number of patents published in the same time period to re-affirm the growth stage of EV industry in the S-curve. The typical indicators for an engineering system (ES), as expounded by GEN3® Partners [2] has been used as benchmark to conclude that the EV industry is currently in its early 2nd stage. Finally, generic recommendations for an engineering system in its 2nd stage have been applied to the EV industry to provide recommendations that are specific to the technology domain.

2. Current Stage of EV – Patent Analysis

To understand the patent activity in the area of electric vehicles, patent search was performed using Thomson Innovation, a commercial patent database. Fig. 1 below gives the number of granted patents as well as patent publications under prosecution as a function of their publication year.

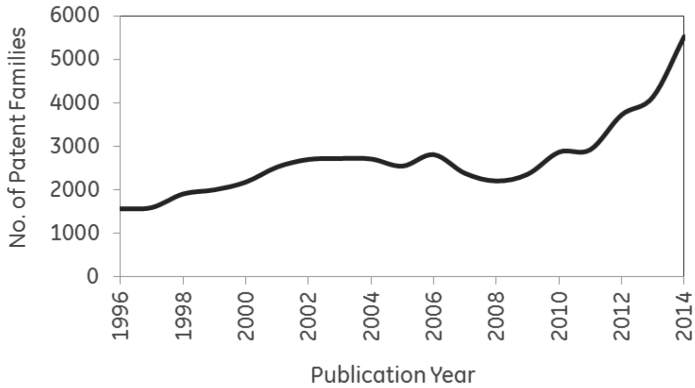


Fig. 1 No. of patent families as a function of publication year for EV technology (1996-2014).

It can be observed from the figure that activities started in the EV technology in mid 1990s. From around 1996, there have been a consistent number of patents getting published every year up until around 2009-10. Beginning 2010, we clearly observe an increasing slope in the number of patent applications getting published each year which indicates an increased focus in the technology segment with higher thrust on research and development happening in this domain.

3. S-Curve Analysis of Electric Vehicles based on TRIZ

In order to facilitate the positioning of the analyzed system onto a logistic curve G.Altshuller proposed the application of three supplementary statistical curves: changes of number of inventions, changes of level of inventions, and changes of profitability during time [3]. Evolution of any technological system usually follows an S-shaped curve that reflects dynamics of the system's performance-to-cost ratio since inception as shown in Fig.2 [4]. When an engineering system approaches the end stage of its development, usually a new system, having a higher performance potential, is already waiting in the wings. Fig.2a is the S-curve for a system, while Fig.2b is a typical plot; "number of inventions as a function of time," for an engineering system and Fig.2c represents the level of inventions.

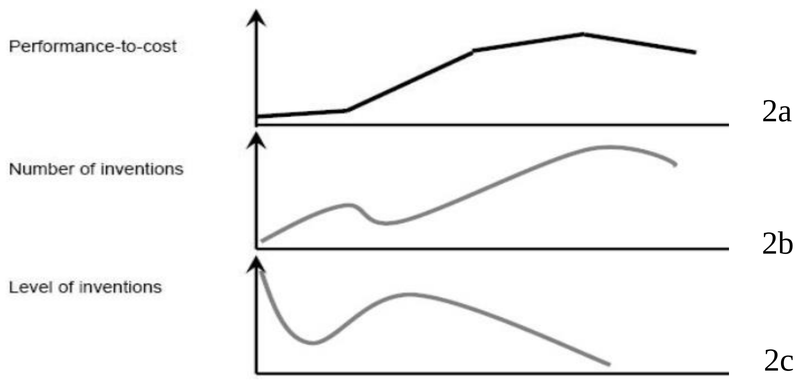
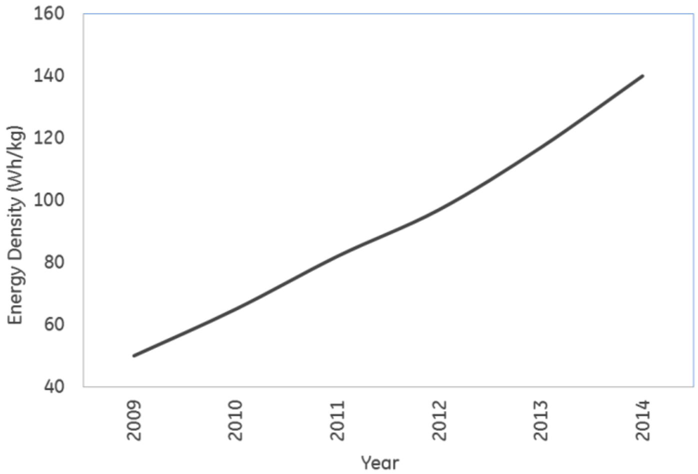


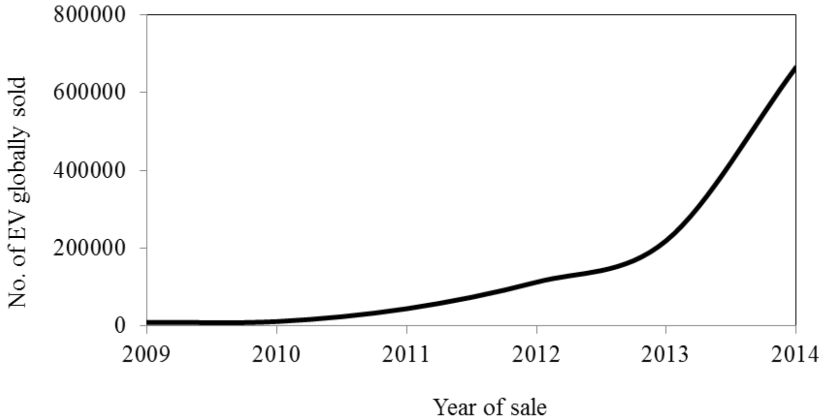
Fig. 2 S-Curve and its correlation with Innovation activity

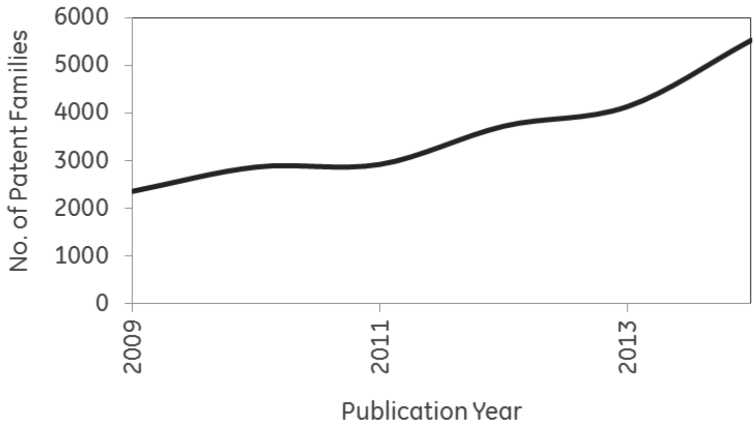
Demand for electric vehicles (EVs) is growing around the world fairly rapidly, according to new analysis from the Centre for Solar Energy and Hydrogen Research, with more than 320,000 new EV registrations in 2014, the total global market grows up to 740,000 vehicles [4] and the international energy agency (IAE) predicts the global EV stock to grow by 24million by 2020 [5]. An attempt is made to understand at which stage of S-curve the electric vehicles are by looking at the development towards increase in the energy density over period of time, the number of inventions over the past 5 years and number of units sold over years. Based on the following three figs 3a, 3b & 3c and using the analogy of TRIZ, it is clear that electric vehicles are in their second stage of S-curve- the growth stage and are ready to dominate the market.



3a

3b





3c

Fig. 3 (a) Energy density over the last 5 years (b) Number of electric vehicles sold globally over a period of last 5 years. (c) Number of patent published in the electric vehicle domain in the last 5 years.

Fig. 3 gives a comparison of the total number of electric vehicles sold vis-à-vis the number of patent publications as a function of time. From the comparison, it is clear that EV industry is currently in the second stage of S-curve.

Now, we shall discuss some of the indicators expounded by GEN3® Partners to confirm our finding that EV industry is in its second stage of S-curve.

Indicators:

1. Engineering System moves into mass production:

From Fig. 3a, we observe that the energy density of the batteries is increasing over the last 5 years, which, in turn, influences the performance of the vehicle. There is a corresponding increase in the number of inventions and global EV sales as shown in Fig. 3b &3c. This clearly shows that EVs are in mass production and increasing their sales rates very aggressively.

2. Engineering System variations become more widely differentiated

Electric vehicles are getting differentiated with respect to propulsion, powertrain technologies and source as well as range of energy [7]. Fig. 4 shows the evolution of different powertrain technologies, with specific focus on electric vehicles. In the first two categories – Internal combustion engines (ICE) & Hybrid electric vehicle (HEV), the major source of propulsion is internal combustion engine. In the subsequent categories, electric motor is the major source of propulsion.

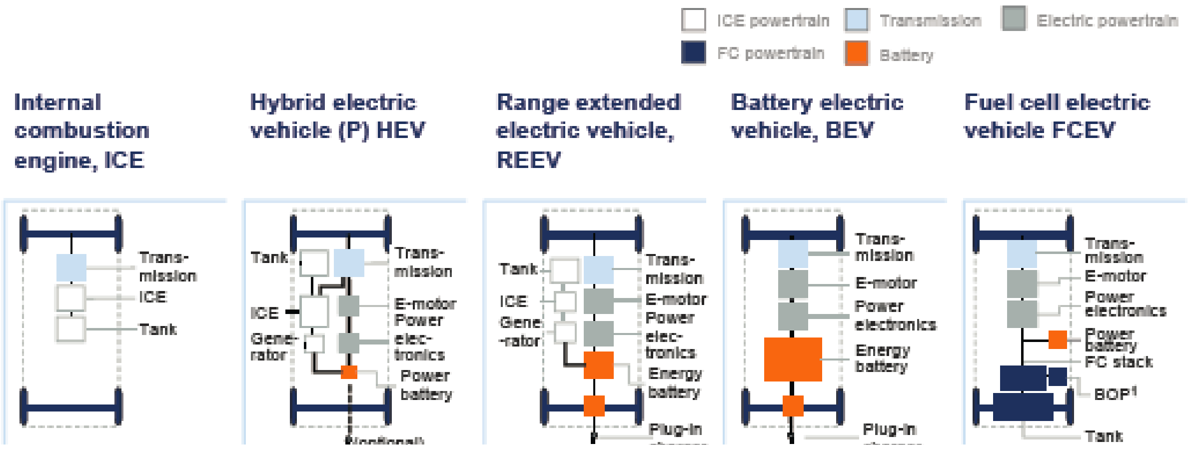


Fig. 4 Different types of powertrain technologies for electric vehicles (Source: Evolution Electric Vehicles in Europe: Gearing up for a new phase, McKinsey & Company)

3. Differentiation between Engineering System's applications increases

Electric vehicles started expanding its application areas from passenger cars to electric trains for entertainment purpose to harsh and critical environments such as mining industry as tow tractors, forklift trucks etc. accommodating the varied needs of different industries.

4. Supersystem elements start adapting to Engineering system

It is observed that the supersystem component such as charging stations have adapted to cater to the needs of electric vehicle industry. This has resulted in electric charging stations becoming a new business segment.

5. Engineering system(ES) starts consuming ES specific resources

Specialized and customized batteries such as Li-Ion and Li-Air technologies are being developed to augment the growth of EV technology segment. This has resulted in creation of new value chain model for EV industry right from development of cell module to assembly of modules to finally resulting in a battery.

These indicators clearly indicate that EVs are in their second stage of S-Curve.

4. Path forward for Electric vehicles:

Based on TRIZ S-curve analysis and indicators present, it was clearly understood that EV's are in its second stage of development and following recommendations are provided for further growth of the industry.

Engineering level improvements: Alternate source of energy for driving electric vehicles can be developed such as Solar based or combination of Fuel cell and Solar based. Novel technologies for improving the efficiency of the vehicle can be developed.

Focus on compromises and solutions aimed at minimizing disadvantages: Two of the major disadvantages that the customer faces with electric vehicles are cost of recharging and battery life. To overcome the issue of cost of recharging, implementation of alternate cost effective sources of electricity for charging the batteries must be explored. EV manufacturers and dealers should come up with a new service model for battery repair and replacement in order to attract larger population to buy electric vehicles.

Develop a competing engineering system: Focus on new materials to develop better batteries with ultra-high power densities can give a fillip to EV industry. For example, more research can be focused towards graphene based ultra-capacitors that in turn can boost the power density of batteries for EV.

Conclusions

In this paper, we have attempted to fit the evolution of electric vehicles industry into the S-curve. The evolution is compared in terms of increase in energy density over time (MPV) vis-à-vis number of inventions over time (as reflected by the patent publications) and global sales numbers. In the process, we have inferred from the potential indicators that the EV industry is in its second stage – the stage of growth. Based on GEN3® Partners TRIZ S-curve methodology, we have provided recommendations for further growth of EV industry. Firstly, the industry should focus on improvements in the engineering system by exploring alternate sources of energy. Secondly, a novel service model needs to be developed by the EV manufacturers in consultation with government in areas like repair and replacement of batteries to boost the EV sales. Finally, research needs to be focused on competing engineering systems, like ultra-high capacitor materials for high power-density batteries, to improve the base engineering system.

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IDENTIFICATION OF CONCEPTUAL DIRECTIONS AT THE INITIAL PROJECT STAGE

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Abstract

There are a number of various recommendations on identification of conceptual directions for engineering system improvement. The authors propose to group solutions into conceptual directions based on implementation difficulty features (short-term, long-term); based on identified components of engineering system; based on specific features of principles used for the elimination of identified problems, etc. But such an approach is very efficient when ideas or concepts of solutions have been already outlined. It is impossible to use them (or very difficult to use them) at the early stage of an innovation project.

The authors suggest outlining conceptual directions by using the developed multi-level flow chart of possible goals for an innovation project. The proposed flow chart of goals for engineering system improvement is based in ideality formula. If a researcher identifies the block of target problem to be solved on this flow chart, he would be able to see and choose possible conceptual directions for future solutions on the lower level.

The authors use this approach in the practice successfully and have good reason to believe that it will be useful for wide circle of TRIZ-practitioners. In addition, the authors do not exclude using this approach by some TRIZ-practitioners. But publications about this approach are not discovered in public sources of information.

Keywords: ideality, concept, idea, conceptual direction, innovation project, project goal, problem solving.

1. Conceptual Directions

Conceptual direction is a group of proposed solutions aimed to improve engineering system and having one or another similar feature. Such features may refer to different aspects of problems inherent to the engineering system or proposed solutions aimed to improve the latter. Grouping solution into conceptual directions allows rational distribution of efforts and means for the purpose of developing various ideas and concepts for engineering system improvement [1, 2]. In addition, at early stages of projects researchers manage to identify the most efficient directions and reject those directions, which are not suitable due to certain reasons.

As a rule, identification of conceptual directions represents a final step of the analytical stage intended for working out ideas or substantiated proposals (in other words, concepts) aimed to improve an engineering system. Traditionally, in this case it is suggested to use the following groups of essential features for the purpose of assigning proposed solutions to one or another conceptual direction [3, 4]:

- components of an engineering system (for instance, it is proposed to improve ES in the following directions: introduction of changes to supersystem components; modification of certain specific components/units of ES; replacement of individual subsystem components);

- degree of changes in an engineering system (for instance, it is proposed to introduce changes in the following directions: replacement of manufacturing technology; radical modification of design; switching over to another principle of action/operation);

- supposed difficulty of implementation (for instance, the following directions: for implementation in the nearest future; for implementation in the not so distant future; for implementation in long-term future);

- key parameters (for instance, the following directions: build up of pressure, decrease in temperature, variation of humidity/moisture content, etc.).

A slightly extended approach is suggested in [1, 5]. The authors additionally propose to generate conceptual directions based on solving tool supposed to be used (for instance, the following directions: direct elimination of key disadvantage, integration with alternative systems, reduction in the number of components, elimination of engineering contradictions, adaptation of solutions employed in other systems).

The opportunity of formulating conceptual directions at earlier stages of innovation project is analyzed in [6]. However, this work is restricted by declaration of purposefulness of conceptual directions identification prior to the beginning of analytical stage and does not offer clearly formulated recommendations.

The necessity of this approach in extended form is analyzed in [7]. The author also gives recommendations on identification of conceptual directions at early stages of work on a project. These recommendations include preparation of images (“portraits”) of proposed innovative solutions prior to the stage of analysis and identification of engineering system disadvantages. Unfortunately, such an approach is characterized by high expenditures and it is not always implementable.

2. Target Approach to Conceptual Directions Identification

Whatever problems need to be solved in the course of innovation projects, an increase in the ideality of an engineering system would represent the final result of the project. This means that the relationship of engineering system functionality to expenditures should be increased. An increase in the engineering system ideality represents the general and final goal of its improvement.

The value of expenditures (in overwhelming majority of cases) could be expressed in monetary terms. The situation with functionality is much more complex. However, monetary equivalent could be also used for functionality. Proceeds, which will be received as a result of consumer/user readiness to pay the asked price for an engineering system having one or another set of functions, represents such monetary equivalent.

Hence, engineering system ideality could be evaluated as the difference between received proceeds and incurred (*Figure 1*).

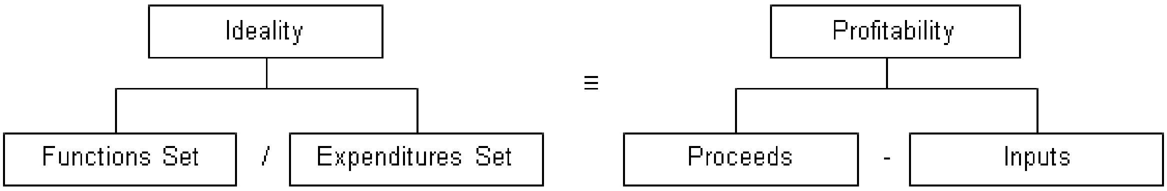


Fig. 1. Equivalent value of engineering system ideality

An increase in this value represents the general goal of engineering system improvement. Obviously, this goal could be accomplished in two ways – increasing the proceeds or reducing the expenditures. These two ways would represent two conceptual directions, if the project goal consists only in increase of profitability (profits).

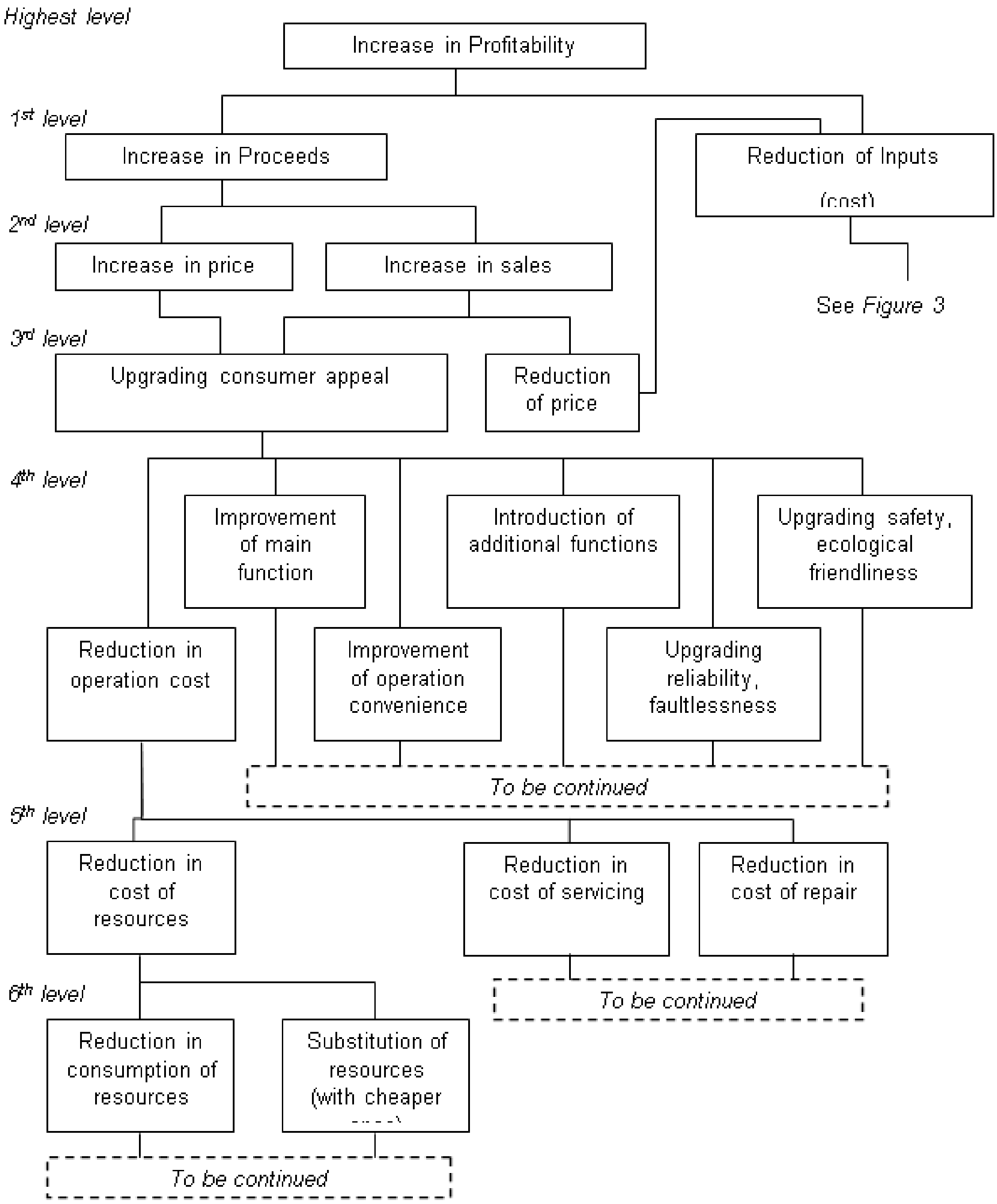
Concurrently, these directions may represent goals of independent innovation projects. Let's call them goals of the first level.

Then, if necessity of an increase in proceeds is set as the project goal (goal of the 1^{st} level), solutions aimed at an increase in sales volume should be included in one of the conceptual directions, while solutions enabling to increase price should be included in another conceptual direction. If it is required in a project to decrease expenditures (another goal of the 1^{st} level), then the following conceptual directions will be formulated: decrease in an amount of fixed costs and reduction of the amount of variable costs. Like in the previous case, these conceptual directions can represent goals of independent projects. Let's call them goals of the 2^{nd} level.

Following the logic described above, one can construct a multi-level schematic diagram of goals of engineering system improvement (see *Figures 2, 3*). If a certain block of a certain level is set as a goal of an innovation project, the directions indicated in blocks located one level lower would represent conceptual directions for solutions aimed at accomplishment of this goal. For example, if a goal of an innovation project consists in the reduction of engineering system operation cost (see *Figure 2,* level 4), the conceptual directions for the search for solutions will be (see *Figure 2,* level 5):

- reduction in cost of resources,
- reduction in servicing cost (making servicing easier),
- reduction in repairing cost (upgrading repairability).

Analyzing schematic diagrams shown in *Figures 2* and *3*, one can draw a conclusion that conceptual directions of higher[1] levels will include solutions grouped based on economic features. Proposed solutions of conceptual directions belonging to lower levels will be characterized by engineering (technical) features. The lower is the level, the more specific is a conceptual direction.



[1]) *High or low level of conceptual direction does not mean higher or lower significance of this conceptual direction.*

Fig. 2. Multi-level flow-chart of project goals / conceptual directions (Part 1)

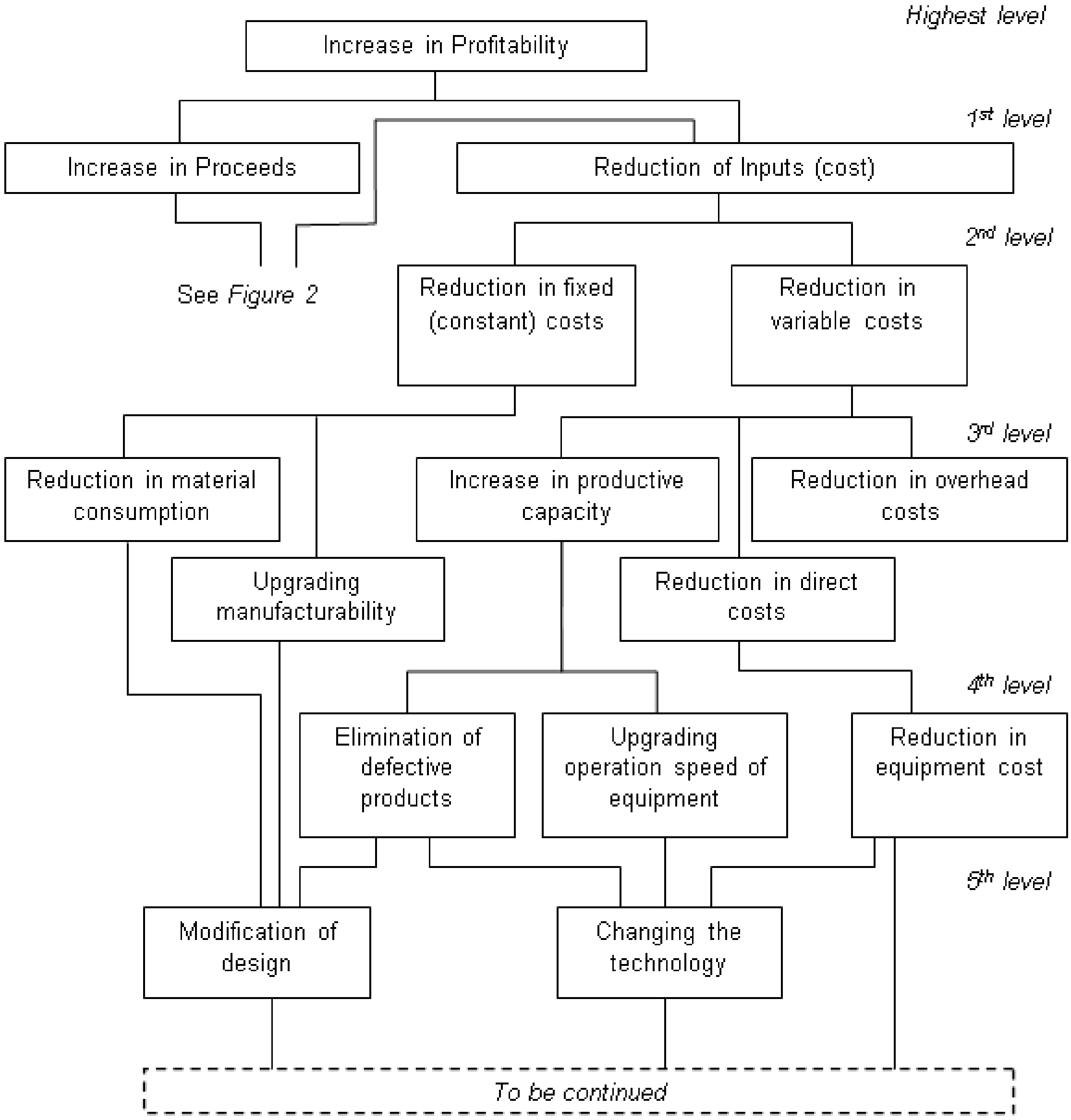


Fig. 3. Multi-level flow-chart of project goals / conceptual directions (Part 2)

3. Conclusions

The suggested goal-based approach enables to identify and choose conceptual directions at the very early stage of work on innovation project. Besides, it also enables to refine the goals of engineering system improvement.

Nevertheless, any approach to generation of conceptual directions is acceptable, if it helps to find the best solutions and accomplish the set goal on engineering system improvement.

Acknowledgements

The authors will be grateful to everybody who would choose to use the above-described method and inform the authors about results obtained through the use of this method. We also will be grateful to those who are willing to introduce substantiated amendments to the proposed multi-level flow chart of goals.

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IN SITU MAGNETIZER WITH TRIZ FROM 6SIGMA PROJECT TO PATENT

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Abstract

Innovation in the electric machine world follows the pattern of system and process integration and a stronger attention is paid to multidisciplinary design rather than to single device topology. Usual design and optimization are often just slightly incremental, aimed to fine tuning optimization. The so-called traditional electric machines have been studied for decades and their further improvement is very much dependent on material research. In fact, during design processes, walls are often hit, as far as topology and performance are concerned. In this scenario problem solving tools like TRIZ can be very helpful to reconsider domain specific problems and identify novel solutions, even when solid processes as Six Sigma come to a stuck point. After a S-Curve analysis of electric machines and a TRIZ application review for this field, an example is offered by the post-assembly magnetization for a permanent magnet electric machine: a highly desirable manufacturing step which has seen so far hardly ever implementation. The review of this issue at GE Global Research Munich by means of Six Sigma tools saw a turning point thanks to TRIZ application bringing to a new concept and a filed patent.

Keywords: electric machines, design, TRIZ, Six Sigma, magnetizer

1. TRIZ for electric machines and drives

TRIZ application in electric machines and drives world is still sparse. S-Curve analyses for electric machines for different main parameters of values, i.e. energy conversion efficiency and delivered torque show that this technology lies definitely on its 3rd stage, confirmed by express S-Curve analysis in Innovation Navigator™ software. Further indicators for this statement are [1]:

- the Engineering System (ES) reaches the physical limits of its principle of action
- engineering limits (material properties)
- high specialized resources
- supersystem components are designed to accommodate the ES

The resulting recommendations are:

- overcome limits, resolve contradictions, switch to another principle of operation

- deep trimming
- find a Main Parameter of Value that is at an earlier stage to develop

TRIZ application examples in scientific publications are still a handful. In the discipline of power electronics, adjacent to electric machines, a big road mapping effort was taken in order to envision the path to 2020 [2], taking into account the physical limits and starting from the interdependence of all single component redefining the operating scenario at a system level. The analysis of the technology development was based on the S-Curve concept with solid mathematic foundation, nevertheless only system optimization was taken into account with respect to single device analysis, and no trends or function analysis were taken into account to allow space for game changing innovation. Consistently, TRIZ has seen so far little application in the field of traditional electric machines. A broad technology analysis under the viewpoint of S-Curve and TESE is hard to find. An historical excursus of the asynchronous machine development was compiled [3], otherwise single application examples regard a power transformer overhaul [4] and in washing machine design [5]. In both examples contradictions were immediately identified and listed with no description of the analysis pre-work. In [6] a more extensive use of TRIZ tools, such as MultiScreen Analysis and a detailed application of contradictions are described for induction machine for submersible pumps.

2. Problem statement: post-assembly magnetization

Manufacturing of permanent magnet (PM) electric machines usually adopts post-assembly magnetization [7]. This implies several critical aspects: PMs are fragile and likely to break during mounting, and important mechanical forces have to be overcome when placing PMs into the high permeable machine structure. Thus post-assembly magnetization would represent a far preferable option. Target of magnetization process is to produce a strong enough magnetic field H such that full magnetization everywhere within the material is achieved. The preferred material for PM machines is NdFeB for which favourable parameters are Br and Hc at lower cost; such magnetic parameters are desirable during machine operation, nevertheless they represent a challenge during the magnetization process, for which a consistent field density of 3T is necessary on the whole magnet. As it will be shown, in the post assembly magnetization solution the requirement that the necessary field is generated with proper orientation at all locations where magnets are disposed introduces a major conflict. In [7] stator windings are used to generate the magnetizing field: in this case it is feasible because the rotor has 4 poles, but this would not be a possible solution for slower and massive machines whose design requires dozens of poles. So the most common layout would take advantage of an external magnetizer. This was the starting point of the Six Sigma project: “Design of an in-situ PM machine magnetizer” in the framework of GE Six Sigma DMAIC steps. The planned pathway is shown in Figure 1:

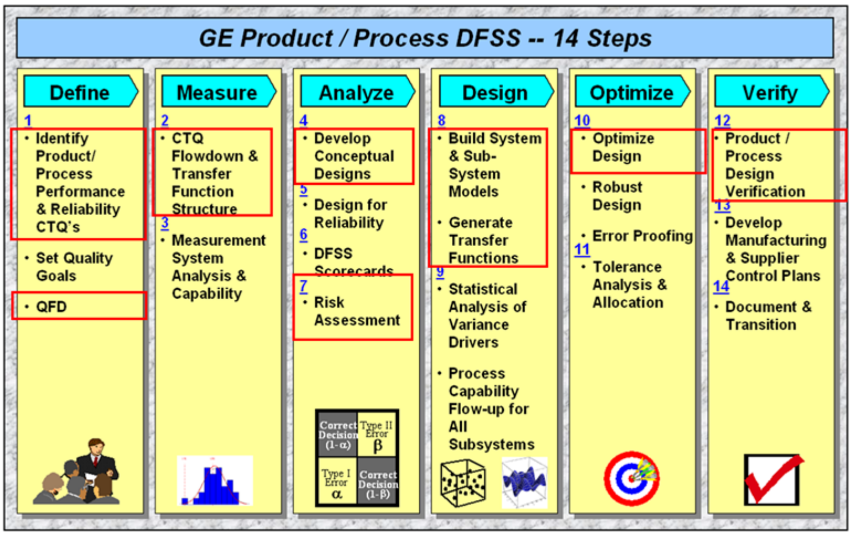


Fig. 1. Project pathway planned before TRIZ application

Critical to Quality project requirements (CTQs) are outlined in Figure 2:

LSL: 3 T in PM region
USL: 500mT elsewhere USL: B uniformity factor < 1

Fig. 2. Six Sigma DMAIC Project CTQs

The quantity *B uniformity factor* σ_{PM} is defined as a function of flux density on selected sample points on the magnet profile:

$$\sigma_{PM} = \frac{1}{2}\sqrt{\frac{\sum_{i=1}^{m}\left(B_{ti}-\overline{B}_{t}\right)^{2}}{m}} + \frac{1}{2}\sqrt{\frac{\sum_{i=1}^{m}\left(B_{bi}-\overline{B}_{b}\right)^{2}}{m}} + \sqrt{\frac{\sum_{i=1}^{m}\left(B_{ti}-B_{bi}\right)^{2}}{m}} \quad (1)$$

where:

m number of measured points

B_{fi}, B_{bi} individual flux densities at the top and bottom surfaces of the magnet, respectively

B, B_b average flux densities over the top and bottom surfaces of the magnet, respectively

Several external magnetizer layouts have been investigated and an outline of the results is given in Figure 3:

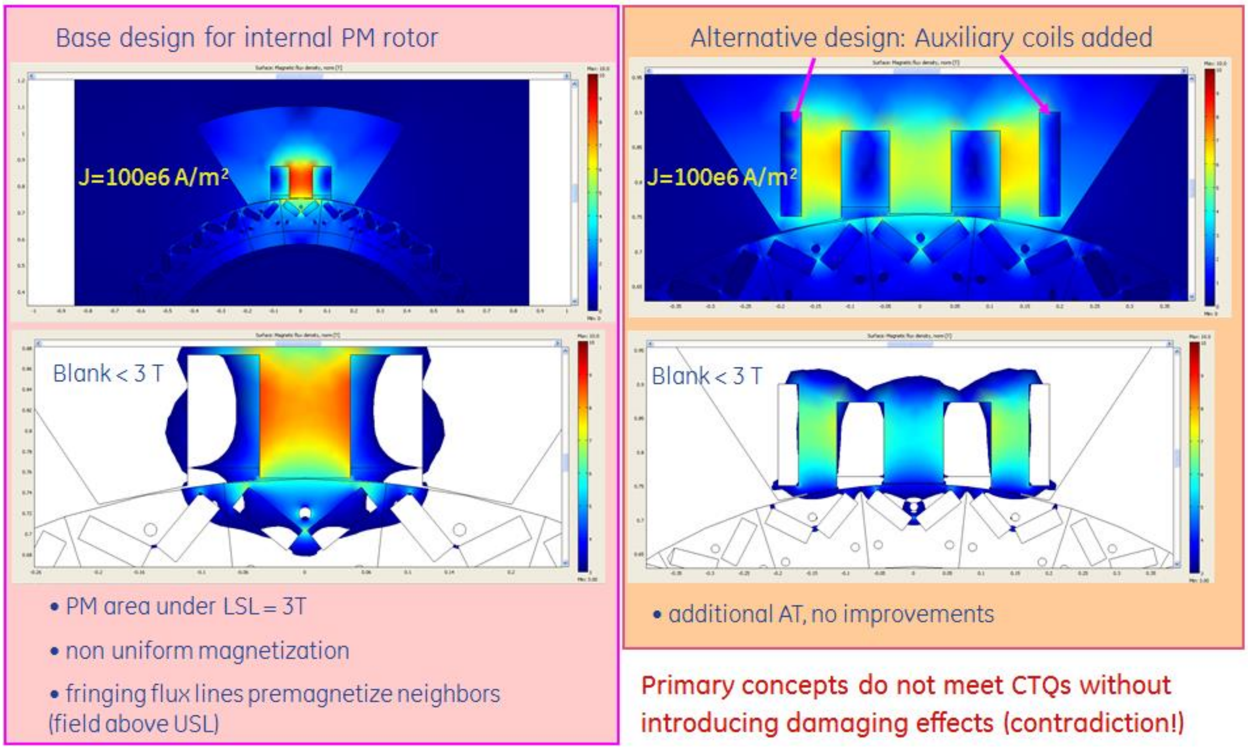
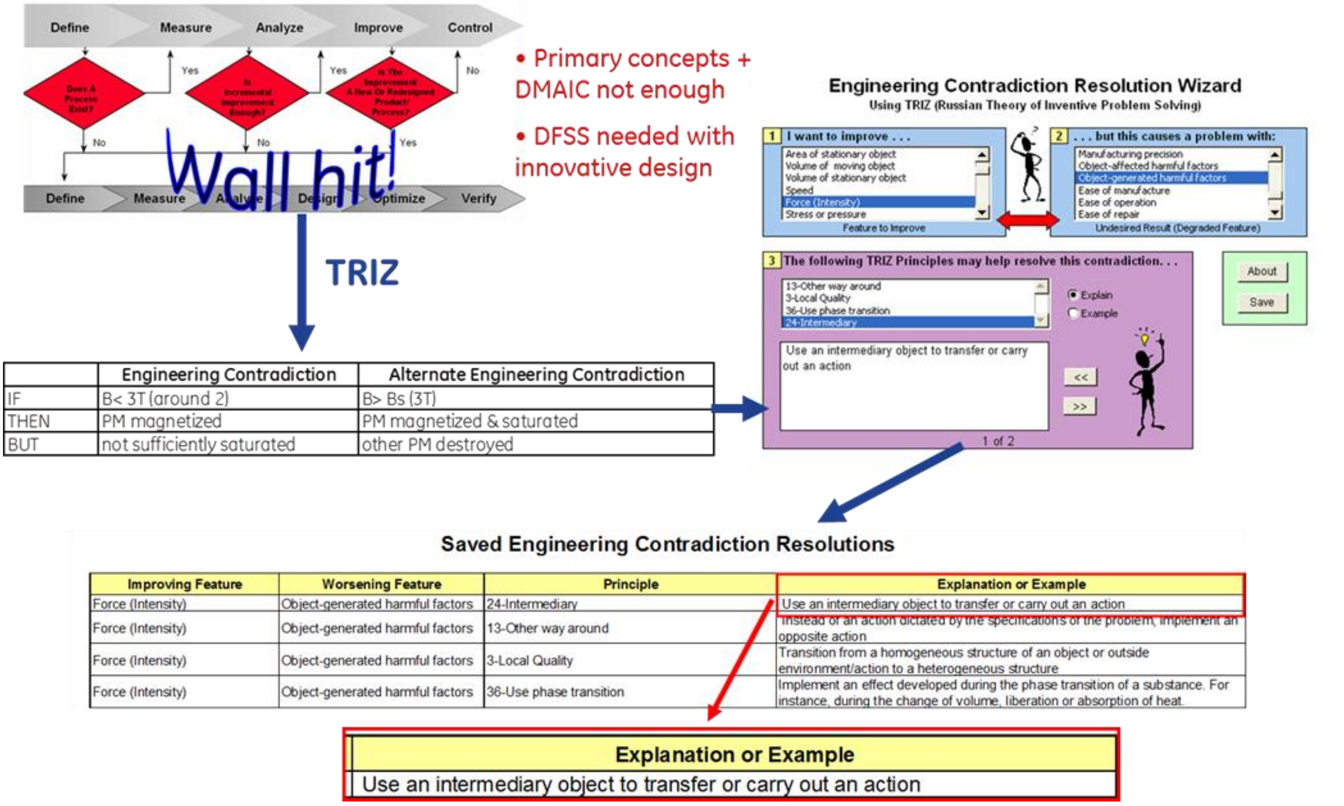


Fig. 3. DMAIC Results

As seen from the Figure 3, the magnet layout is such that a complete reversal of the magnetic field in few millimetres is needed, which is nearly impossible to achieve with a regular external magnetizer. If it happens for the first magnet, the adjacent ones also see the same magnetizing field resulting in their irreversible pre-magnetization, which impairs the subsequent magnetization in the required direction. So the pre-assembly magnetization seems to be the only feasible option, even if bringing already magnetized magnets close to each other brings about manufacturing difficulties because of the resulting mechanical forces. In the Six Sigma framework the steps Define, Measure and Analyse have been performed, during which it resulted clear that the traditional optimization approach for an external magnetizer would have failed in meeting the required CTQs, introducing damaging effects as a result. In other words, the application of DMAIC for primary concepts was not enough and a DFSS with an innovative design was needed to overcome the problem. At this point TRIZ came in place.

3. TRIZ Modeling

After the Define Phase of DMAIC the problem constraints led to a “hit wall” situation in the process, so the need of an innovative design emerged. This stuck point in the project reflected the impossible goal to achieve a suitable value of the B field at the needed locations, identifying conflicting requirements that lent themselves to be translated immediately into engineering contradictions, which in turn reflected precisely the CTQ demands. Figure 4 shows how the engineering contradicting rising from the flux density requirements for the NeFeB piece under magnetization and its neighbours is formulated in a GE proprietary tool, translated into the contradiction between the conflicting parameters Force/Intensity(to be improved) and Object generated harmful factors (not to worsen). The Altshuller's Matrix suggests in this case four inventive principles.



	Engineering Contradiction	Alternate Engineering Contradiction
IF	B< 3T (around 2)	B> Bs (3T)
THEN	PM magnetized	PM magnetized & saturated
BUT	not sufficiently saturated	other PM destroyed

Improving Feature	Worsening Feature	Principle	Explanation or Example
Force (Intensity)	Object-generated harmful factors	24-Intermediary	Use an intermediary object to transfer or carry out an action
Force (Intensity)	Object-generated harmful factors	13-Other way around	Instead of an action dictated by the specifications of the problem, implement an opposite action
Force (Intensity)	Object-generated harmful factors	3-Local Quality	Transition from a homogeneous structure of an object or outside environment/action to a heterogeneous structure
Force (Intensity)	Object-generated harmful factors	36-Use phase transition	Implement an effect developed during the phase transition of a substance. For instance, during the change of volume, liberation or absorption of heat

Fig. 4. TRIZ application by means of a GE proprietary MS Excel-based tool

For completeness sake, the same problem was formulated as physical contradiction in the Innovation Navigator™ Tool in terms of flux density, which is required to be high and low simultaneously at very close locations as shown in Figure 5:

Physical Contradiction	Way to Resolve	Direction	Recommended Inventive Principles
B field Should be High In order to Saturate Magnets BUT B field Should be Low In order to not to spoil neighbouring magnets	Separating Contradictory Demands	Separation in Space	1. Segmentation 2. Taking out 3. Local quality 7. 'Nesting doll' 4. Asymmetry 17. Another dimension
B field Should be High In order to Saturate Magnets BUT B field Should be Low In order to not to spoil neighbouring magnets	Separating Contradictory Demands	Separation in System Level (Hierarchy)	1. Segmentation 5. Merging 33. Homogeneity 12. 'Equipotential'
B field Should be High In order to Saturate Magnets BUT B field Should be Low In order to not to spoil neighbouring magnets	Separating Contradictory Demands	Separation in Time	15. Dynamics 34. Discarding and recovering 10. Preliminary action 9. Preliminary anti-action 11. In-advance 'cushioning'

Fig. 5. Physical contradictions in Innovation Navigator™ Tool

4. From TRIZ Specific Solution to Patent

The contradictions suggested that the magnetization should have happened as closed as possible to the magnets so that neighbouring magnets were protected and current density in the coils could be reduced. Among the inventive principles recommended by the Altshuller's Matrix, the ones resulting for Separation at System level were not pursued further since the they did not appear to be of immediate help, as well as the principles 13, 3, 36, 1. Principles 33,1 2, 11 sounded promising but did not solve the conflicting requirements at the same location (magnets) at different times (during magnetization of one magnet and the subsequent magnetization of its neighbour). The most effective principles resulting from the Application of Separation in Space, Separation in Time and from Engineering Contradictions were:

7 – Nesting Dolls (PC, Separation in Space)

34 – Discarding and recovering (PC, Separation in Time)

24 – Intermediary (EC)

These principles pointed to the observation that the magnetization could have been performed by coils not associated to an external magnetizer (24- Intermediary) and that such coils were no longer needed once the magnetization was completed (34-Discarding and Recovering). Moreover, it was noticed that in proximity of every magnet there were voids at both sides for mechanical reasons: they offered the chance to place magnetizing coils exactly where they were needed with much less excitation requirement with respect to the one given by an external magnetizer. This led to the new conceptual design shown in Figure 6, where such voids were used for placing temporary auxiliary magnetizing coils to be removed just after the magnetization process.

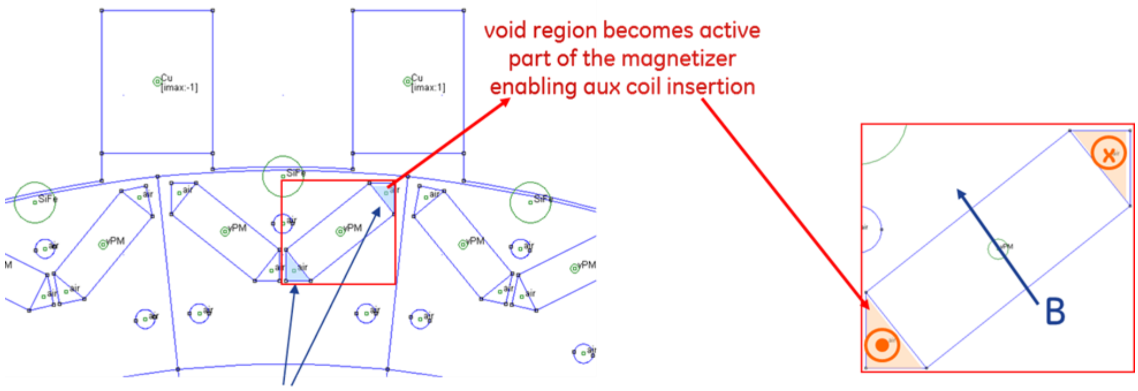


Fig. 6. Physical Concept substantiation

Another recognizable Inventive Principle for this solution is:

6 – Make a part or object perform multiple functions, eliminate the need for other parts (EC)

The peculiar features of the invention were:

- void regions became active parts of the magnetizer enabling auxiliary coil insertion
- from one single big external magnetizer we moved to a segmented, smaller and local magnetizer
- the magnetic field is reinforced exactly where it was needed
- the magnetic circuit was small and local so no big magnetomotive force was required to compensate magnetic potential drops along the big external magnetic circuit
- smaller coils and thus smaller power supply sizing was needed.
- all the magnets could magnetized at once, thus saving time

Simulation work with the aid of Finite Element Analysis proved the technical feasibility: with the new small local coils (whose section is limited by the voids, so as not to change the topology of the magnetic circuit of the machine) an adequate magnetization is obtained with realistic current densities, preserving integrity of neighbouring magnets, as shown in Figure 7:

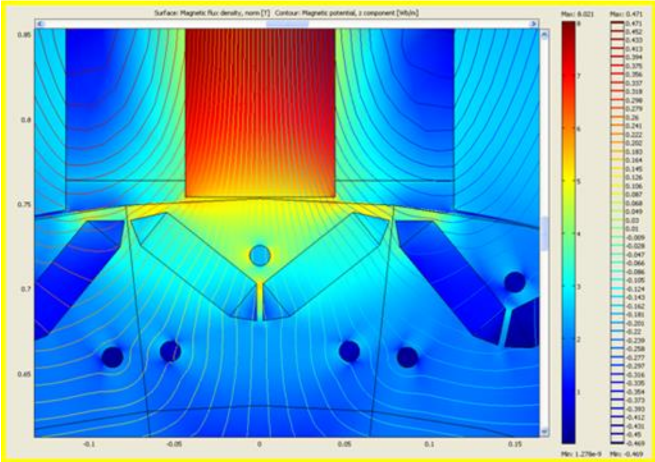


Fig. 7. Flux density obtained with auxiliary coils

Table 1 shows that new concept satisfies the Six Sigma DFSS quality requirements:

Table 1

6Sigma concept validation

		Initial Concept	After DFSS Optimization	FEA Verification
Xs	unit	x	x	x
x_v	mm	0	-2	-2
y_v	mm	0	681	681
y_h	mm		211.02	211.02
sigma_main	A/mm^2	100	68.084	68.084
sigma_aux	A/mm^2	0	80	80
B_av_PM	T		3.0003	2.998
Zst		-8	7.650	
sigma_PM	#		0.961	1.000022
Zst		-8	8	
overall Zst			7.759	
overall Zlt			6.259	

This concept was successfully claimed by GE and a patent was granted.

5. Conclusions

Innovation process in electric machines is thought to be slowly reaching its limits, to be pushed by material research breakthroughs. Even if the technology is mature and the S-Curve analysis suggests starting to investigate for alternative approaches, TRIZ can be surprisingly helpful to find technology enablers and new solutions in this field. It fits naturally in the Six Sigma process offering a bridge between DMAIC and DFSS, taking advantage of the Define and Analyse steps for a more straightforward implementation. Its application, not yet very broad for power electrical engineering, can successfully lead to novel solutions and patents.

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TRIZ*fest* 2015

INPUT VAT RECOVERY

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Abstract

Global FMCG Company was producing and selling millions bags of snacks in Poland per annum. In order to increase an attractiveness of the product inserts (small plastic discs) with a picture of football players, Pokemon, or other famous characters were placed into the plastic, sealed bag. The input VAT on these discs was 22%. The output VAT for final product in bags was 7%.

The producer was not allowed to claim the input VAT (22%) on promotional inserts, which created an additional cost element, which was not tax deductible from the CIT (Company Income Tax perspective. The existing VAT rules were not clear enough which created ambiguity. Hired Consultants from two of Big-4 Consulting Firms were arguing with the Tax Office for 4 years without any success.

With a support of tools and methods proposed by TRIZ - author was in position to design, propose and implement effective and cheap solution resulted in recovery of few million dollars of historical VAT.

Keywords: Ideal Final Result, Multi Screen Diagram, Root Cause Analysis, VAT, Tax Office.

1. Problem identification and documentation, potential benefits

Big FMCG organization was performing marketing activities through placing inserts (e.g. Pokemon) into bags of snacks, however the Tax Office interpretation was as following:

1. Input VAT (22%) on purchased inserts was not possible to deduct from the output VAT (final product had a 7% VAT rate) when products were sold to customers

2. Cost of inserts was increased by 22% of input VAT, which was not tax deductible from the CIT perspective.

3. Selling final product to customers the Company needed to apply two different VAT rates on the same sealed bag: 7% on packed bag of snacks and 22% on insert being placed in the same bag.

The yearly input VAT on inserts was equal to USD MM 0.4-0.8 per annum and total value exceeded USD MM 3.0 in a period of 1998-2002.

Two Consulting Companies were assisting the Manufacturer with that problem, however without any positive results. Plenty of requests were sent to the Tax Office, Tax Chamber, Ministry of Finance in 4 years, questioning logic and bases for such treatment of inserts from CIT and VAT perspective.

Company was getting one standard reply from each place which was saying : “in relation to your interpretation request, hereby we confirm that everything what the Company is doing - is correct“.

One of the principal VAT tax rule in Poland says that after passing 5 years from date of transaction, any tax claim related to such transactions is expired. The Author, working for the Company as Financial Controller, being responsible for all statutory and US GAAP (Generally Accepted Accounting Principles) matters - started to consider how to address this subject as there was below 50% chance to recover historical VAT. Therefore he decided to approach to the matter using TRIZ tools and methods [1,2,3,4].

Finding an effective solution would result in:

1. recovery at least part of historical VAT being paid

2. rationalization of A&M (Advertising & Marketing) expenditure and material costs in the production process

3. elimination of tension, frustration and time wastage of the Company employees related to unproductive activities and debates with the Tax Office and Tax Consultants.

2. Problem analysis and diagnostics

2.1 Multiscreen Diagram

The following table presents a multi-screen diagram of the situation (Table 1).

Table 1

	Past	Now	Future
Super System	Due to an ideology reasons (Communism time) Entrepreneurs were perceived by State Administration as fraudsters and criminals. So high profits were as a premium for risk taken. (Grey zone in Polish economy generated +30% of the GDP.)	State Administration is using its power to introduce what they think is right and "take care on the State budget" – as a result of that some good and big businesses collapsed in Poland. (Grey zone – in 2015, 23% of the GDP [5].)	State Administration see Entrepreneurs as partners and supports them in developing businesses. The wealth of the nation depends how good all people cooperates in the Country. (Grey zone <10% of GDP. (2014 NL = 9,2%) [5].)
System	The VAT was introduced since 1993. Entrepreneurs were acting under huge psychological pressure due unpredictability of the Tax Office decisions / reactions / interpretations on the CIT and VAT matters	Different interpretations of Tax rules by T. Office and tax payers. There is lack of willingness from the TO side to support businesses. Tax Offices issue different interpretations of the same rules depending on their location in Poland.	There is not disconnection between Tax rules and practice. Local Tax Offices provides with an advise to tax payers. Entrepreneurs and Tax Administration have similar goals. Interpretations of the Tax Rules are the same across the whole country . Tax Office supports business.
Sub Systems	People working on the CIT / VAT Tax Returns in the companies were under huge psychological pressure. Chief Accountant was a key person in the business decision making process in every business.	People working on the Tax Returns are working under lower pressure, but Tax Consulting Firms have a good business. Management Accounting is more important that Financial Accounting.	Simpler and faster job related to Tax Returns. Having rules standardization – easy to automate the process fully, can be cheaper. Outsourcing is the common solution. Entrepreneurs concentrate on business.

2.2 RCA – Roots Cause Analysis [6]

To analyse the causes of the problem, classical Root Cause Analysis (RCA) was performed. Figure 1 presents its results.

The RCA uses the competency model as per Recommendation of the European Parliament as per the document - 'Key Competences for Lifelong Learning — A European Reference Framework' (2006/962/EC), 18th of December 2006.

Competences are defined here as a combination of Attitudes, Skills and Knowledge and appropriate to the context. Key competences are those which all individuals need for personal **fulfillment** and development, active citizenship, social inclusion and employment.

The "Culture" element of the RCA diagram is based on the Hofstede model of cultural dimensions [7], Fig 2.

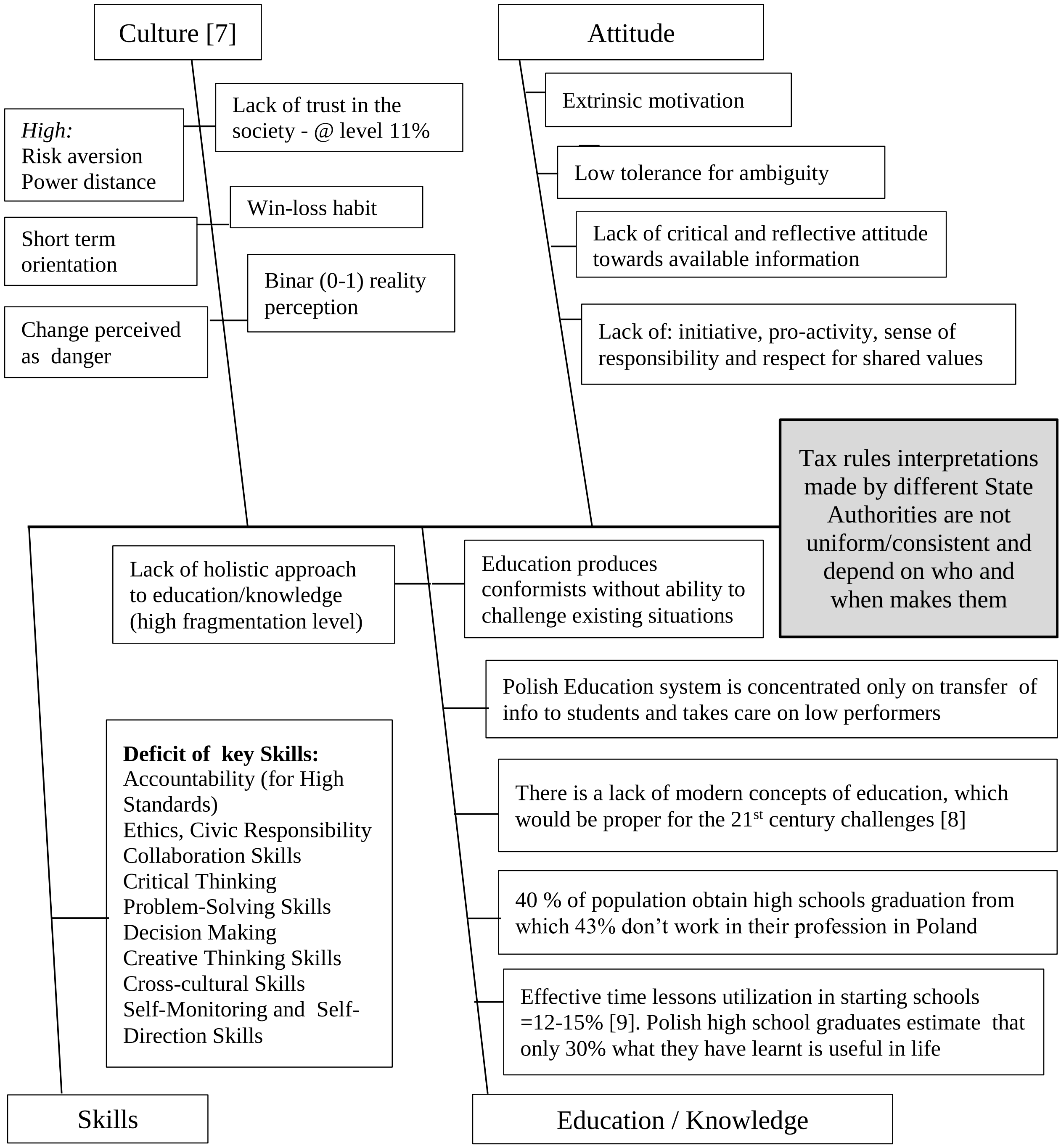

Fig. 1. Results of the RCA Process

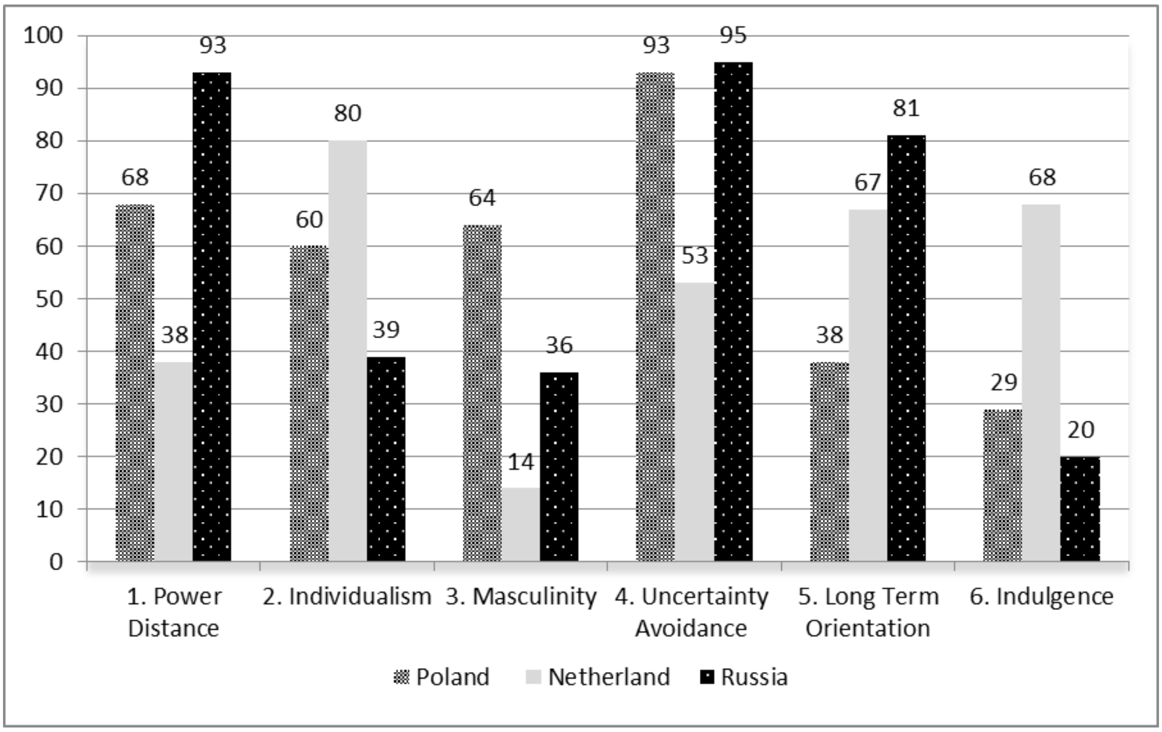

Fig. 2. Cultural Dimensions: Poland with comparison to Netherland and Russia (source: http://geert-hofstede.com/poland.html)

2.3 Conclusion

Based on the presented results, especially in the areas of the Culture:
- high Power Distance,
- high Uncertainty Avoidance, and
- low Long Term Orientation Indexes,

characterizing people in Poland and taking into account other elements as low trust level, a binary reality perception and “win-loss” habit - the only way to clarify an existing situation with the VAT on insert was a Court verdict.

In order to initiate the Court case – the Company needed a legally binding decision issued by the Tax Office, which could be appealed. The problem was that the Tax Office was avoiding to submit any formal decision – they responded in a form of opinion only, which could not be a subject of an appeal.

3. Contradiction identification and solution proposal

The situation described above indicates the following contradiction:

If the Company followed the VAT rules and Tax Advisors interpretation in deducting the input VAT on inserts, then got better Cash Flow position and lower costs, but at the same time was exposed to the negative reaction of the Tax Office and accusation of lowering the tax liability (if the sum exceeds USD 1300 this is an crime in Poland).

And opposite:

If the Company followed Tax Office interpretation – then avoided accusation, but were exposed to higher costs and worse CF position.

Having an experience with the Contradiction Matrix for Engineers [2] and knowing the list of inventive principles for Business and Management by Darell Mann [10], the Author considered three inventive principles:

- Principle 9. Preliminary Anti-Action
- Principle 10. Preliminary Action
- Principle 13. The Other Way Round

After detailed consideration the no. 9 principle was chosen – preliminary anti-action.

4. Ideation - IFR - Ideal Final Result

One of the TRIZ tool and a method of determining the progress in problems solving is the IFR, which represents a concept of ideality. Ideality is defined using a following formula:

Ideality = [Sum of Benefits] / [(Sum of Costs –Sum of Harm)]

The basic assumption of the IFR evolution is increasing benefits while decreasing costs and harm associated with the new solution.

The IFR attempts to reduce or eliminate the deficiencies of the old system while maintaining the advantages. The IFR does not make the new system more complicated nor does it introduce new challenges [11].

The IFR definition is not influenced by considerations if it is possible to achieve the ideal and how it should be done. . It serves as a major guideline for the best solution.

The main rule of the IFR strategy: do not speculate beforehand whether or not it is possible to achieve the ideal result. When formulating the ideal final result, psychological barriers and a mental inertia should be avoided.

Switching from “impossible” to “it works” helps to overcome the fear of unusual, daring solutions [12].

So, in that specific situation, the Ideal Final Result would support the Company in confirming the following (based on the ARIZ methodology):

What is the final aim?

the VAT process itself would allow clarification what would be allowed (or what not) to do with the input VAT deductibility and cost price element CIT deductibility.

What is the ideal final result?

Make VAT and the cost CIT deductible in full without spending any effort.

Why does this interfere?

Interpretation of VAT and CIR rules by the local Tax Office.

Under what conditions would the problem disappear? What resources are available to create these conditions?

When the Company gets a legally binding decision from the Tax Office which could be challenged in the Court (Superior Administrative Court).

Resources needed: human resources with a proper ‘can do’ attitude, imagination, TRIZ knowledge, critical and creative thinking.

5. Ideation - IFR - Ideal Final Result and backwards questions

Get the right to recover the input VAT and CIT deductibility of the cost of inserts.

5.1 Circumstances under which we the Company can recover the VAT – what triggers recovery ?

The only chance to recover the VAT is a situation in which we have in hand a final decision (but not an interpretation) of Tax Office, Tax Chamber or Superior Administrative Court saying that the Company to do so.

Tax Authorities submit a decision every time after Decision after making the Company tax audit and finds something against existing rules.

According to the Polish Tax Code, if the tax deficit found during the Tax Audit is under USD 1300 – this is treated as an offense resulted in medium fiscal penalty (USD 1000-2000) for the responsible person (e.g. Financial Controller), however when the tax deficit exceeds USD 1300 – it can be treated as a crime – with serious fiscal penalty (> USD 20 K) and with a legal case against Board of Management Member responsible for Financial matters.

However if the Company finds any tax incorrectness and report that case as soon as possible to the Tax Office itself, there is possibility to avoid a responsibility and the penalty is limited to the interest only - 21% of the main liability p.a. (as of Aug 2002).

5.2 What is a chance of success (success defined as VAT recovery) and when ?

The success probability (recovery of historical VAT) in a conservative way was estimated at the level of 50%.

It could be time consuming, as the first instance is Tax Office, then Tax Chamber and finally

– Superior Administrative Court. So, it could take minimum 2-3 years in Polish conditions.

In the worst case scenario – the Company would obtain a clarity how to proceed with the VAT in the future.

5.3 What was the final proposal how to proceed with the VAT ?

A. The purpose was to use the principle no. 9 – ‘preliminary anti-action’ would induce the Tax Office to make an audit and submit a decision – then the Company could appeal it.

B. As usual, at the 25th day of each month the Company filled the VAT form in, however the Company deducted the input VAT on inserts at value of USD 30 K.

C. After 3 weeks the Company found the 'omission' and inform the Tax Office in a written from on that, adding a phrase that *'however the Company's position is that it was proper VAT treatment'*.

6. Conclusions

6.1 Tax Office reaction

In 7 days after the Company informed the Tax Office about its finding – few Tax Inspectors came to perform an audit and after few weeks Tax Office submitted a formal, legally binding decision asking the Company to adjust VAT and CIT registers and pay the interest penalty – which was an equivalent of USD 1K.

6.2 Final

Decision from the point no. 5.1 being received by the Company, was challenged by Tax/Legal Advisors working for one of the Big4 Consulting Firm (working for the Company on a success fee basis).

The whole process took almost 2.5 years and finally the Company got the legally binding decision from Superior Administrative Court confirming that:

- the Tax Office interpretation related to VAT treatment methodology on inserts was wrong

- the Company has a right to adjust the VAT register since October 1998

- the Company has a right to apply lower VAT rate (7%) for total value of finish goods

Since then the Company had a right to change he procedure and to make an adjustment to deduct an equivalent USD MM 2.5 as an input VAT five years backwards, obtained from the TO interest rate at value of USD MM 1.0, and got the income tax shield at value of USD MM 1.0. – total benefit was equal to USD MM 4.5.

Based on that precedent one of the biggest local competitor of the Company recovered USD MM 1.0 in the next 6 months.

Acknowledgements

Hereby I would like to show my gratitude to the Founder of ICG T&C – Valeri Souchkov for sharing his knowledge with me and his inspiration to prepare this paper.

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MYTRIZ JOURNEY IN MALAYSIA

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Abstract

The Malaysia TRIZ Innovation Association (MyTRIZ) was formed in 2010. It has embarked on 3 strategies namely to: (i) create a national platform which focuses on ensuring TRIZ training delivery, standardization, and quality; (ii) create a learning platform which focuses on proliferating TRIZ to schools, universities, and industries, while creating new products, services, or systems; and (iii) create a sharing platform by organizing TRIZ conferences in order to generate momentum, share learning and best practices, and advance methodology application.

Although the association is considered relatively young, it has grown quite significantly in terms of growth of MyTRIZ Level 1 practitioners which has exceeded the 5,000 mark within 5 years. The latest MyTRIZ Conference 2014 was a 4 day event consisting of conference, workshop, competition, and community service; and had a record 1,024 participants. The uniqueness of the MyTRIZ association is the holistic support of industries, government linked organizations, and government ministries. This has enabled a steady growth of TRIZ in Malaysia. The TRIZ momentum is growing with much interest and enthusiasm across schools, universities, and industries.

Keywords: TRIZ, MyTRIZ, Innovation, Malaysia, Intel, MDeC

1. Introduction - the early days

TRIZ in Malaysia was started via Intel Corporation when a total of 14 personnel from various countries were certified to MATRIZ Level 3 by Dr. Sergei Ikovenko and Mr. Alex Lyubomirskiy from GEN3 Partners in 2005. An Intel TRIZ team was formed to develop customized training material for in-house training. This was then followed by respective teams working with various organizations across Intel worldwide to teach and apply TRIZ in order to demonstrate its effectiveness.

Out of these 14 personnel, 2 were from Intel Malaysia and thus started the TRIZ journey in Malaysia. Internal TRIZ Level 1 training workshops were conducted in Malaysia towards the end of 2005. Initial two workshops managed to create breakthrough solutions even for problems which were more than 3 years old and on equipment which were as old as 10 years. Based on the quick and elegant solutions which were derived, upper management decision was to propagate TRIZ to all Intel manufacturing sites which included China, Costa Rica, Malaysia, and Philippines. This activity took ~3 years (from 2006 till 2009) to complete where 3,500 personnel were trained. In addition, projects were also worked on during the training with significant success.

As the TRIZ momentum gained popularity in Intel, there was an interest as to whether TRIZ could be proliferated nationwide in Malaysia, instead of just limiting to company level. Discussions with a government linked organization namely Multimedia Development Corporation (MDeC) resulted in a positive response. At that time, MDeC was looking for more effective problem solving methods to improve skills of knowledge workers. Similarly, Intel was focused on education as part of their Corporate Social Responsibility (CSR). A series of discussions went into the strategies. It was decided that TRIZ would be proliferated to three sectors namely schools, universities, and industries; with initial focus on universities. So, in 2010, a 3 year Memorandum of Understanding (MOU) was signed between Intel, MDeC, and Ministry of Higher Education (MOHE) to proliferate TRIZ to academia.

2. MyTRIZ formation

In order for TRIZ to be properly managed in terms of its standards for certification, teaching, and proliferation; the Malaysia TRIZ Innovation Association (MyTRIZ) was founded by Mr. Eng Hoo Tan (MDeC), Dr. KH Siek (Intel), Dr. KM Yew (MDeC), and Dr. TS Yeoh (Intel), in 2010. The committee members consisted primarily of lecturers and deans from both public and private universities/colleges; with Intel and MDeC providing the leadership and stewardship for the association. Once the association was formed, numerous activities kicked in especially in the creation of the short term and long term strategies for the association. The following were the strategies which were developed in 2010, and they have remained essentially intact with further enhancements over the 5 year duration.

3. MyTRIZ Strategies

Altogether, there are 3 strategies as listed below:

a) Strategy #1 is to create a national platform with primary focus in the formation of MyTRIZ to ensure quality of teaching, learning, and practice; drive implementation of training plan and govern certification process; and market methodology, successes, and best practices.

b) Strategy #2 is to create a learning platform by: (i) developing and adapting TRIZ training curriculum to the local environment, define a Malaysia level TRIZ training and certification roadmap, and train academia with the aim to proliferate methodology at universities; (ii) training selected industry specialists to promote methodology and application at companies with the aim to enhance the problem solving and innovation capability, solve national issues or develop emerging opportunities, and create new products, services or systems, (iii) simplify and adapt TRIZ curriculum to primary and secondary school level and train school teachers with the aim to teach methodology as elective programs, develop school projects to apply methodology and showcase successes at science and technology competitions.

c) Strategy #3 is to create a sharing platform by organizing TRIZ conferences to generate momentum, share learning and best practices, and advance methodology application.

Details of the strategies are as follows.

3.1. Strategy #1 - Creating a national platform

This strategy is focused on enabling academic lecturers to be able to conduct TRIZ Level 1 training to their students. These lecturers are required to undergo training and certification on MyTRIZ Level 1, MyTRIZ Level 2, and MyTRIZ Level 1 Instructor. On completion of training and passing the certification test, a certificate is issued by MyTRIZ. The MyTRIZ training material is aligned to the MATRIZ syllabus. The instructors for the lecturers are MATRIZ Level 3 certified practitioners from Intel. Intel funds the instructor's travel and lodging as part of their CSR, while MDeC funds the training material in line with their knowledge worker upskilling initiatives. Essentially, there were no fees charged to academia based on the MOU which lasted from 2010 till 2013. Altogether, ~3,000 lecturers have been certified to MyTRIZ Level 1.

Once the lecturer is certified to MyTRIZ Level 1 Instructor, he/she is provided with the necessary training material. The lecturer can conduct MyTRIZ Level 1 training and certify their students accordingly. This can either be through weekend classes or be embedded as part of the university curriculum.

There has been much interest generated especially among academia, along with an increased interest from the industries. Currently, there are 5,689 MyTRIZ Level 1 practitioners, 242 MyTRIZ Level 2 practitioners, 31 MyTRIZ Level 3 practitioners, and 95 MyTRIZ Level 1 instructors. Ultimately, the strategy is to certify MyTRIZ Level 3 practitioners to MATRIZ Level 3.

A MyTRIZ website (http://mytriz.com.my/) was created as a source for news and upcoming key events, along with membership application submissions. Similarly, a Facebook group has also been created (https://www.facebook.com/groups/TRIZ.MALAYSIA/), and this has garnered much interest including international TRIZ enthusiasts.

3.2. Strategy #2 - Creating a learning platform

As TRIZ gained momentum among the academic staff, the interest was not solely from the engineering based lecturers, but it gained the interest of lecturers from various fields including management, finance, accounting, architecture, and many more. The course material was subsequently revamped in order to accommodate a broader based audience.

As a result, TRIZ has propagated not just to the academia, but has also generated interest in the industry. The industries are varied ranging from automotive, garment, electronics, medical, agricultural, and construction. In order to promote TRIZ application in companies, an additional day is devoted to working on projects ranging from technical to people related problem solving, and from tactical to strategic product/service innovation. In most cases, a follow-up project review is done on subsequent months for project closure. On average, it has been found that 30% of projects reviewed can be resolved within the first review session. If a follow-up review session is held, an additional 30% of projects can be further resolved. The breakdown of projects is as follows: Yield improvement/defect reduction (58%), Productivity (21%), Research & Development (9%), Customer returns (6%), Sales/marketing (4%), People (1%), Safety (1%). Figure 1 shows the growth in MyTRIZ Level 1 practitioners at a 53% Compound Annual Growth Rate (CAGR) from 2010 till 2014.

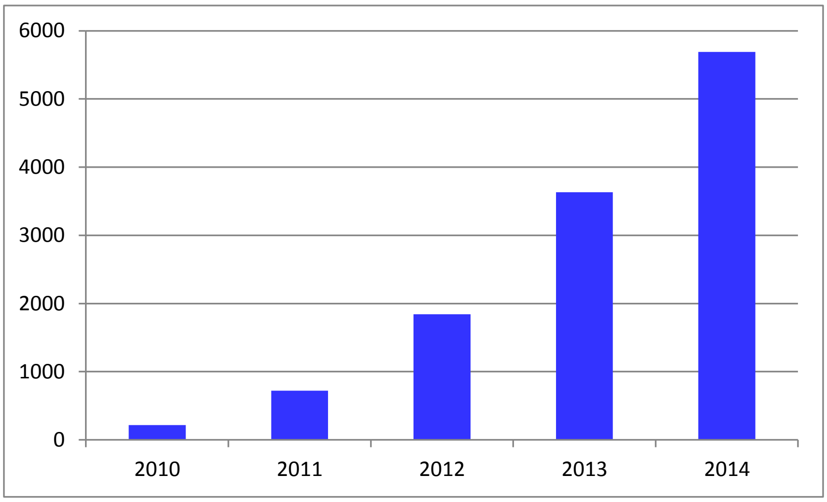

Fig. 1: MyTRIZ Level 1 practitioner growth

In order to sustain the continued application of TRIZ in the academia, the MyTRIZ Competition was initiated in 2012. Teams had to create a new product which costs less than US$30. They also had to demonstrate the application of TRIZ on a more complex project. The number of participating teams has grown from 34 teams initially in 2012, to 79 teams in 2014. The incentive to be in the top 8 teams for the finals is not just the prize money, but having an opportunity to productize and commercialize their inventions as there are government linked organizations who are on the lookout for local inventions.

There has also been much interest from the Ministry of Education (MOE) in terms of how TRIZ can assist in promoting Higher Order Thinking Skills (HOTS). MyTRIZ has conducted training for 150 MOE curriculum developers based on Education for a New Era (ENE) course material in 2014. The ENE training named School for Creative Thinker Workshop was originally conducted by Mr. Anatoly Guin and Dr. Mark Barkan in Malaysia in 2013. This training has initiated much interest in the area of open problem solving and creativity thinking.

3.3. Strategy #3 - Creating a sharing platform

One of the major activities was to create the publicity and awareness of TRIZ through seminars, conferences, and competitions. The first MyTRIZ conference was organized in 2010. The highlights included presentations from local and international TRIZ speakers, official launch of the MyTRIZ association, along with a media press conference and interview.

There were a total of 150 participants from Multinational Companies (MNC), Small & Medium Enterprises (SME), consultant firms, and government agencies. Intel assisted in getting regional attendees from Japan, Vietnam, Thailand, Korea, Sri Lanka, Pakistan, Philippines, India, and Taiwan.

The MyTRIZ conferences have grown over the years in terms of activities and number of attendees reaching a total of 1,024 in MyTRIZ Conference 2014, with a 61% CAGR (Figure 2). The fees charged are minimal as the conferences are fully funded by many entities including Intel, MDeC, along with other public and private organizations.

The latest conference in 2014 was named Pesta TRIZ (similar to TRIZ Festival in translation) which was a 4 day event consisting of conference, workshop, competition, and community service. The conference featured 4 international speakers and 5 local speakers, while the community service was focused on teaching open problem solving to 300+ school children from 6 schools.

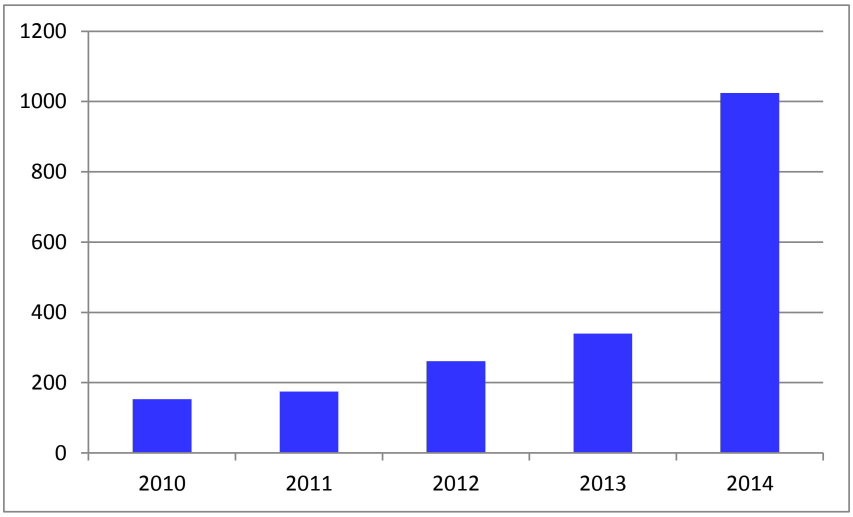

Fig. 2: MyTRIZ Conference attendee growth

4. Conclusion

Although TRIZ in Malaysia is considered relatively young, it has grown quite significantly in terms of growth of MyTRIZ Level 1 practitioners which has exceeded the 5,000 mark within 5 years. Similarly, lecturers are incorporating TRIZ into their academic course curriculum. In some universities and colleges, all their final year engineering students are MyTRIZ Level 1 certified. The MyTRIZ conferences, workshops, and competitions have also generated interest both locally and abroad. There has been an increased interest from the South East Asian countries especially in Thailand, Indonesia, and Philippines.

The uniqueness of the MyTRIZ association through the support of industries, government linked organizations, and government ministries; has enabled a steady growth of TRIZ. However, there is still much to do especially in demonstrating TRIZ impact in creating new products, and proliferation into schools in order to assist in higher order thinking skills and creative thinking amongst children and youth. TRIZ in Malaysia is a journey and as the TRIZ community grows both locally and internationally, the TRIZ brand will become more established and recognized.

Acknowledgements

The authors would like to thank Dr. Siek Kah Hee and Dr. Yew Kok Meng who were instrumental in the formation of MyTRIZ. Special thanks to the MyTRIZ committee members who have contributed towards the growth and proliferation of TRIZ in Malaysia. Finally, gratitude goes to Multimedia Development Corporation (MDeC), Intel Foundation, Intel Malaysia, Institution of Mechanical Engineers Malaysia, and the various government agencies including Malaysia Productivity Corporation (MPC), 1M4U, and Ministry of Education (MOE), for their continued support for MyTRIZ.

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NETWORK ANALYSIS OF TRIZ PRINCIPLES AND CONTRADICTION MAPS TO RECOMMEND RESEARCH ORIENTATION AND PATENT STRATEGY

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Abstract

Development of a patenting strategy is imperative for a company to protect its IP portfolio. This paper explores various means of incorporating TRIZ for evaluating a patent landscape to develop a research path and support it with a patenting mechanism. The approach incorporates TRIZ and S-curve analysis to gage the state-of-art and predict direction of technical progression. The results are compared with insights obtained from patent landscape. A set of dominant TRIZ principles defining the technology are identified and related to the maturity level of the industry, and also to the protection policy that needs to be employed.

Keywords: TRIZ, S-curve analysis, principles, contradiction analysis, technology trends, patent strategy.

1. Introduction

Patent portfolio of a company or a technology domain has, traditionally, been analyzed to draw insights into the strengths and weaknesses of the company as well as threats posed. This analysis could further provide information on areas where there are no filings (white space analysis). However, it is often noticed that white space available for patenting is necessary but not sufficient [1] without mention of the direction to pursue. Thus, traditional method of patent analytics predicts neither the most probable direction(s) of growth nor the means of achieving them. Such recommendations are devoid of realistic representation of the patent space and do not account for the dynamic nature of patents and technologies. Addressing the concerns described above, we have developed a novel process to identify research orientation by combining patent analytics with TRIZ methodology. To this end, we have extracted requisite data from a sample set of a particular patent portfolio and employed feasibility matrices, TRIZ principle growth patterns and contradiction analysis to evaluate the portfolio from an evolution point of view. These trends have been further assessed to hypothesize possible research modes and associated patenting mechanisms thus imparting dynamism to the suggestions.

2. Literature Review

Liu et al.[2] carried out a top-down approach to use TRIZ effectively. They provided guidelines on patent analysis by combining number of patents and their citation count. Further, they introduced system operator concept that analyze the trichotomy of super-system, system and sub-system from a time perspective by associating technique employed with effect realized. Mann[3] introduced the concept of evolutionary potential by combining technical trends with business trends. This comprehensive list allows establishing the present maturity level of a system and chalking out its probable residence in the future based on its potential. Several case studies are provided to elucidate the metric of evolutionary potential and growth patterns. Schuh et al.[4] describe a framework for TRIZ based technology intelligence and illustrate how TRIZ analysis can be used for technology planning. The methodology developed is based on systems theory, morphology and technical evolution that assist in SWOT like estimation of competing technologies. They further describe trends using S-curves based on patent analysis.

Tompkins et al.[5] used patent analysis to determine the evolutionary status of digital imaging technology using CCD and CMOS chips. Maturity of the technology has been analyzed in terms of number of patents per year, inventiveness of the patents and performance. Further, applicability of trend analysis and TRIZ tools for future product development has also been exemplified. Janghyeok et al.[6] considered the evolution of systems by analyzing patents for properties and functions. By combining natural language processing and binary relations, evolutionary potential is generated which are used for technology forecasting. Janghyeok et al.[7] develop an automated process to extend grammatical combinations and patents to construct technology growth curves. Von-Wun et al.[8] worked on a similar theme and combined natural language processing, ontology and patents to develop heuristics to resolve contradictions in design and engineering parameters. They further support this study using a chemical mechanical polishing case study. Similar to Janghyeok et al.[6], Verhaegen et al.[9] propose an algorithm to establish trend phases which map the corresponding evolutionary stage and its potential, insights which are subsequently used to suggest product improvements. Stratton et al.[10] couple TRIZ and the theory of constraints to develop a process of systematic innovation to marry commonality of the two methods. Contradictions are then studied and applied to a production scenario.

From above, it is clear that technology prediction from patents and evolution strategies are important. However, it is evident that recommendations of research orientation have not been addressed. The procedure proposed in this paper attempts to address this particular need. Further, expansion to patenting mechanisms based on the advised scientific inquiry path is also accomplished. The methodology developed is explained below with a case study.

3. Methodology & Case Study

The developed methodology is described below using an engineering system of a solar cell, a multi-layered structure that converts light to electricity (see Figure 1). Each step of the algorithm is detailed by incorporating the engineering system to fortify novelty and impact of this innovative procedure.

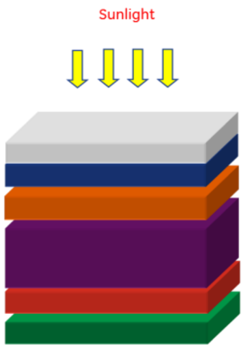

Fig. 1. Typical solar cell

1. *Choose* a technology domain of interest - The engineering system selected for analysis is a photovoltaic device that converts sunlight to electric current using a multi-layer structure.

2. Identify the set of representative patents - Using the conventional patent search, a set of 300 patents has been retrieved.

3. Identify the main parameter of value (MPV) - Since the device is a power generating module, conversion efficiency has been chosen as the MPV of interest. The MPV or the Main Parameter of Value is the chosen metric to compare the selected engineering system in terms of its functionality.

4. Extract patents from the Step 2 that numerically disclose the MPV – Of the 300 patents, 25 records has been shortlisted where the MPV has been quantified. This is the sample space to be further analyzed.

5. Identify critical records from the sample space – Three pairs of critical records, (US4260427A, US4319069A) in 1981 – 1982, (US5304499A, US5472910A) in 1994 – 1995 and (US5472910A, US5557146A) in 1995 – 1996 have been identified where the disclosed MPV values are at least 10% larger than the previous record (condition for criticality). Thus critical records are defined as those pairs of records where the MPV in the latter has increased by at least 10% over the former.

6. Develop feasibility matrices for the critical records – Every engineering system is characterized by its design, material properties, manufacturing method employed apart from the intended functionality. Each of these domains and their interplay offer insights into the performance of the system. Contrasting them is thus useful to obtain the inherent characteristics of the system. Hence, analyzing the key domain comparisons beginning with design vs. materials, it is clear that the design of the device (see Figure 2) has standardized to a multi-layer structure with marginal improvements in efficiency.

(p-ZnTe/i-CdTe/n-CdS)			10.7%
N-n-p or n-p-p		10%	
Aluminium	6.8%		
	Current collector grid as FC	3 layer semiconductor structure	3 layer semiconductor structure
	1986	1988	1990

Fig. 2. Design vs. materials

For the second comparison,

CdTe						13.8	
CdS & CdTe					13		
II-VI semiconductor				13			
Ion-exchange membrane		13					
Substrate							11.8
Ohmic contact			11.6				
Doped CdTe	10.3						
	Electrode position	Electrodeposition	Sol-gel	All-dry method	CSS	Chemical deposition	Transporting substrate
	1989	1993	1995	2001	2002	2003	2007

Fig. 3. Materials vs. process

it is evident that choice of fabrication method and conditions of the selected process are critical to achieving higher efficiency.

HgTe+CuTe in graphite for back contact				15.8%					
CdS:O (9-15%)						15.4%			
Silicone layer on glass substrate								14%	
CTO with spinel structure					13.7%				
Barrier layer between substrate & TCO									12%
Halogen containing layer between CdTe & metal contact							11.8%		
Te comprising layer between CdTe & metal contact		10%							
FTO			9.5%						
n-CdTe with Cd-rich layer at the ohmic contact interface	6%								
	Interface	Interface	TCO	Back contact	TCO	Oxygenation	Interface	Substrate	Interface
	1981	1982	1983	1996	1999	2005	2008	2009	2010

Fig. 4. Materials vs. materials

Finally, notice that material combinations and coupling is a vibrant space, with multiple viable opportunities and a diverse set of options available for different layers of the cell structure.

1. *Isolate key findings from Step 6* - Of the three sets of contrast, material choices, process selection and process parameters are more vital than design configurations.
2. *Identify the top 5 TRIZ principles from the sample space* – Enumerating TRIZ principles divulged in each of the patent in the sample space of Step 4, and collecting the top 5 principles gives -

Table 1

Top 5 TRIZ principles isolated from the sample space

Ranking	Principle Number	Number of Occurrences	Description
1	40	24	Use of multiple materials
2	30	21	Use of thin layers
2	24	21	Use of intermediate layers
4	35	11	Changing process parameter values
5	32	9	Use of transparency

1. *Build transient curves for the top 5 TRIZ principles* - The top 5 TRIZ principles listed above are plotted (cumulative) against decadal time to observe and evaluate trends emerging from the growth patterns.

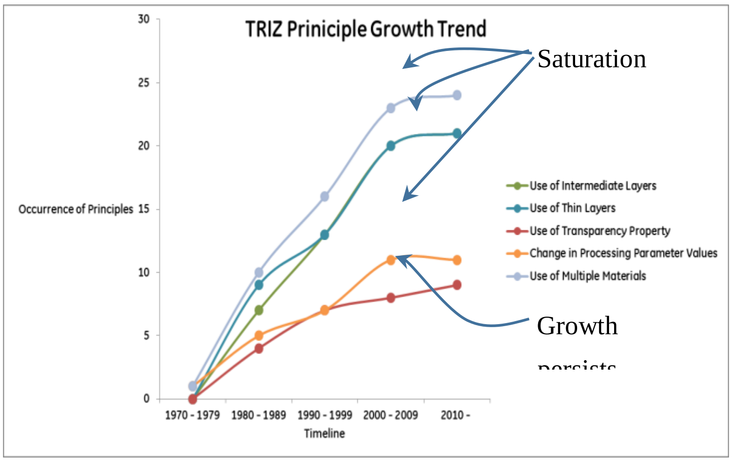

Figure 5. Trends in top 5 TRIZ principle cumulative growth

2. *Identify steady-state and growing curves* - Use of thin layers and multiple materials appears to reach a steady-state condition along with changing processing parameter values to some extent. Work in optics and, choice, arrangement and number of intermediate material layers continues to be in vogue. Statistically, no conclusions are drawn due to lack of data but mere observations are made.
3. *Identify contradictions* - As every patent tries to resolve a contradiction, contradiction analysis has been performed. Pairs of TRIZ generalized parameters and the mutual contradiction observed in such pairs, are extracted from each of the patent in the sample space of Step 4. For instance, if patent 1 discloses TRIZ generalized parameters x_1 and x_2, then the inherent contradiction between the two parameters is isolated. Such contradictions are then checked for contextual relevance *i.e.*, is the contradiction pertinent to the photovoltaic device. A sample set of the contradictions is summarized below.

Table 2

TRIZ contradictions observed in the sample space

Pairs of Parameters	Improving Parameter	Worsening Parameter	Applicable?	Contextual Interpretation
21, 39	Power (21)	Productivity (39)	Yes	A process enabling increased power output at the cost of reduced productivity (by increasing processing step(s) or time of a particular process)
21, 27	Power (21)	Reliability (27)	Yes	A process enabling increased power output at the cost of reduced reliability
27, 22	Reliability (27)	Loss of energy (22)	Yes	Increasing the reliability at the cost of reduced efficiency
22, 27	Loss of energy (22)	Reliability (27)	Yes	Reducing the energy loss at the cost of reduced lifetime
22, 21	Loss of energy (22)	Power (21)	Yes	Reducing the energy loss at the cost of reduced power output
21, 22	Power (21)	Loss of energy (22)	Yes	Improving the power output at the cost of increased energy loss

4. *Build the contradiction network map* - Based on the contradiction analysis, a network map has been constructed to capture interactions between the observed TRIZ contradictions in the sample space of 25 patents, using the notation shown.

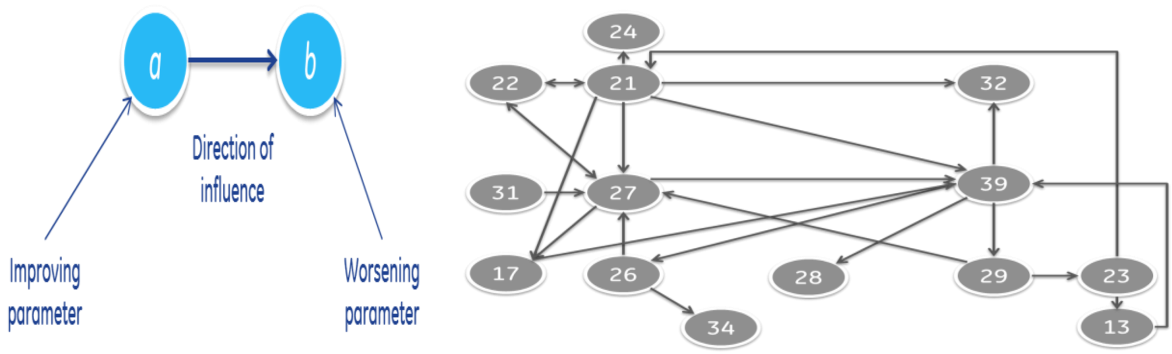

Fig. 2. Network map of contradictions

5. *Analyze the contradiction network map of parameters*
   - Ordered pairs (**21, 22**) and (**22, 27**) are self – contradicting *i.e.*, there have been patents that have focused on improving parameter **21 (or 22)** while worsening parameter **22 (or 27)** in the process and vice-versa.
   - Let *I* denote the index of the node *i.e.*, number of connections to other nodes (parameters). Then,
     - ✓ $I_{21} = 7,\ I_{27} = 7, I_{39} = 8.$
     - ✓ Key parameters are thus, 21, 22, 27 and 39.

Analyzing the positive dependence (direction of influence) of each of these parameters from the map, we have –

$$(17,\ \mathbf{22},\ 24,\ \mathbf{27},\ 32,\ \mathbf{39}) = f(\mathbf{21}) \rightarrow \text{System Equation}$$

$$(\mathbf{21},\ \mathbf{27}) = f(\mathbf{22}) \rightarrow \text{Constraining Condition}$$

$$(17,\ \mathbf{22},\ \mathbf{39}) = f(\mathbf{27}) \rightarrow \text{Constraining Condition}$$

$$(26,\ 28,\ 29,\ 32) = f(39) \rightarrow \text{Independent of the System}$$

Notice that parameter **39** is independent of **21**, **22** and **27** and hence can be discarded. Hence the optimization problem for the technical domain would be –

$$\left.\begin{array}{l} 21\uparrow = f'(17,22,24,27,32,39) \longleftarrow \text{Objective} \\ \left.\begin{array}{l} 22\downarrow = f'(21,27) \\ 27\uparrow = f'(17,22,39) \end{array}\right] \longleftarrow \end{array}\right\} \text{TRIZ State Equations}$$

Thus –

- Parameter **21** is intended to be increased, which is a demand of the industry.
- Parameter **22** affects **21** and **27** negatively, and hence should be decreased.
- Parameter **27** affects **22** negatively and hence should be increased, which would then couple with the previous condition constructively.

6. *Establish research orientation* - Based on steps 7 through 13, research should be oriented towards - Keeping parameter **22** (loss of energy) at a minimum or constant, while improving parameter **27** (reliability) for increased values in parameter **21** (power) i.e., transparency needs to be improved so that scattering and reflectance of light is minimized so that greater conversion efficiency can be obtained. Material combinations and their production are crucial for enhanced power output.

Further, pairing the three critical parameters listed above – (**21, 22**), (**22, 27**) and (**21, 27**), results in three recommendations from the TRIZ standard solution matrix.

- ✓ Exposure to oxygen rich environment and ionizing radiation.
- ✓ Installing prior protection.
- ✓ Skip certain destructive operations.

Validating these recommendations, it is observed that exposure to oxygenated environment has improved the efficiency of a photovoltaic cell [11][12]. Further, Dhere *et al.*[13] have demonstrated that adhesion problem (loss of reliability) in the fabrication process was resolved using interfacial layers (prior protection), which contributed to improved efficiency values. They have also shown that usage of $CdCl_2$ after the deposition of CdS reduced device performance (destructive operation that needs to be removed). Summarizing, increasing efficiency values in photovoltaic cells is primarily dependent on material choices and their fabrication (as predicted in step 7), augmenting transparency (from step 10) and following the process parameters of step 13. The observation made earlier in the paper about materials and their manufacturing taking precedence over design is duly vindicated. Thus, the new procedure of TRIZ analysis proposed in this paper is strongly supported by technical evidence and is robust.

7. *Recommend patenting strategies* - In the near-term (5 years or less), where incremental changes in efficiency are expected, the technology protocols that are hypothesized include –
   - Optimization of choice, arrangement and number of layers.
   - Development of designs with least number of layers wherein one or more of the layers performs more than one function.
   - Removal of unwarranted processes or process steps while in operation.
   - Increase in robustness with the inclusion of protection features.

   where protection of *article* and *method* referenced in the statutory classes [14] is logical. Scope of claims should cover and extend to several different design configurations, sequences in processes and combinations of the two. In the long-term (more than 5 years) where significant jumps of efficiency are anticipated, probable scientific practices embraced could be –

   - Use of lasers/microwaves/other field sources for bonding and conditioning.
   - Use of layered manufacturing at optimum conditions.
   - Research in materials which display enhanced optical transmittance with reduced electrical impedance.
   - Research in μ-scale and *n*-scale material models.

   where protection of all statutory classes of *matter, article, machine* and *method* is mandated, claim scope could broadly encompass, apart from those listed above, material choices and concentration levels, functional and structural variations in materials, modes of manufacture, methods of material preparation and optical properties of new age materials. We have observed from various research activities that some of the above recommendations have been employed resulting in an enhancement of the efficiency of the CdTe based PV modules.

4. Conclusions

An innovative methodology (with potential for generalization) to conserve time and effort in research has been proposed. The key aspects of the methodology are –

- Understanding the maturity level of a technology.
- Establishing feasible combinations of domains and engineering principles.
- Mapping TRIZ principle growth trends used for saturation estimations.
- Network analysis of the resolved TRIZ contradictions.
- Prediction of possible research orientations in the near-term and long-term.
- Recommendation of patent strategies to protect the research modes.

Thus, a mechanism for portfolio assessment using TRIZ has been provided where a novel application with a 2-tier validation has been shown. A combined prediction-protection methodology has been setup wherein researchers are given an idea of particular areas of interest which would allow for incremental and significant innovations, while the legal community is provided with a framework to protect such developments, both in the near-term and the long term.

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NUMERICAL CONSTRUCTION OF S-CURVES USING THE TRIZ TOOL OF TRENDS OF ENGINEERING SYSTEM EVOLUTION (TESE)

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Abstract

Evaluating maturity stage of a product is important to understand remaining life of the device and to plan for its next offering or potential retirement. Currently, S-curves are employed to map the product to an appropriate part of the curve based on market, functionality, cost and design information. We propose and develop a novel procedure in this paper where construction of S-curves is performed using quantified metrics. Hence, the key research problem addressed in this paper is how the maturity level of a product can be estimated mathematically and how such indices can then be used to trace an S-curve to highlight the relative positioning of such products. By combining Trends of Engineering Systems Evolution (TESE) and product features, we build measurable metrics (TESE scores) first, another novelty introduced in this paper, that are then used to ascertain the current stage of product evolution. We present an example of a set of audio devices to highlight robustness of this innovative methodology.

Keywords: TRIZ, S-curve analysis, TESE, MPV, product maturity, feature maturity, growth index

1. Introduction

The consumer product market is hugely competitive and turn-around time for a new product launch is fairly short. It thus becomes mandatory for an organization to gage its own product life cycle to keep abreast of the market drivers and, adjust and align product development phases accordingly. Conventionally, product maturity level has been associated with S-curves where functionality and costs are the indices used to deduce the stage that the product is currently rated at for a chosen MPV. The S-curve [1] has 5 distinct stages (*First, Transition, Second, Third and Final Stage*) distributed in three zones (*Incubation, Growth & Saturation*). Each zone (*Constant, Increasing and Constant or Decreasing gradient*) is characterized based on functionality offered by the product and associated costs (see Fig. 1). By coupling these two variables, an evolution curve can be construed that is indicative of the current state of the product and also suggests path to be employed to further growth in product acceptance [2]. Assume that maturity level of a product is denoted by its ideality [2] –

$$M_i = \frac{F_i}{C_i}$$

where i is the stage in the evolution curve. In the *first* and *transition* stage, the gradient of functionality and cost, signifying ideality and thus maturity, remains stagnant. In the *second* stage, ideality and maturity dramatically increase while in the *third* and *final* stage, ideality again saturates or reduces implying maturity either begins to taper off or reduces. Ikovenko *et al*. [3] provides indicators for identification of each stage.

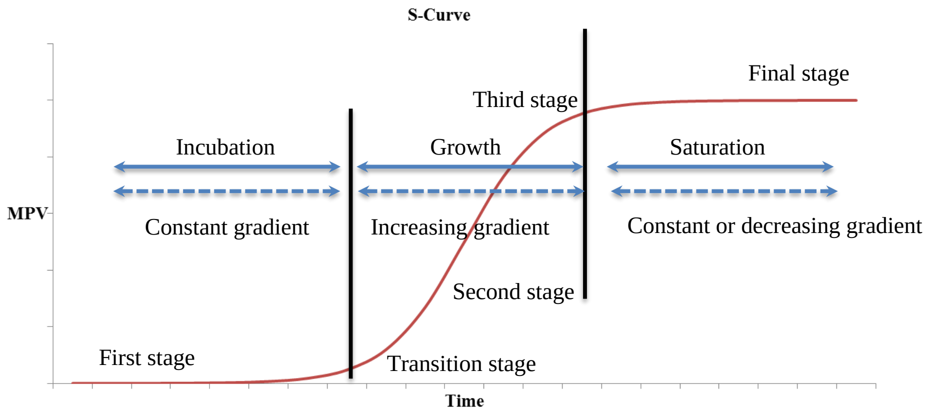


Fig. 1. S-curve with stages, zones and function-cost gradients

The ideality index thus becomes a guideline for building the S-curve. Since TRIZ allows for evaluation of functionality as well [3], and when cost data is publicly available, establishing the ideality value is fairly straightforward. Further, as ideality and maturity are equated, maturity indices are identical to ideality values. Discrete values of ideality hence provide for the construction of S-curve or the maturity plot. The additional benefit realized from plotting S-curves is to graphically observe the changing pattern which allows identifying *progressive vs. Disruptive* products depending on the current state of the product. However, presupposition of TRIZ knowledge to capture functionality and/or availability of cost numbers is extremely limiting. Therefore, there exists a genuine need to generate an S-curve construction process that is intuitive even to the novice and is independent of cost. A paradigm shifting procedure is presented in this paper specifically catering to this stark need. Note also that the proposed formulation is distinct from the earlier known product life cycle or product life management modules in that we neither discuss patenting or sales activity nor describe market penetration of products or life of a product. We rather focus on the features and operating mechanisms provided in the product, to estimate its technical stage indicator in each of the 3 zones (*Incubation, Growth & Saturation*), by incorporating all 9 TESE trends spread across the entire X-axis. In this paper, we use TESE suite of TRIZ methodology as the scale or basis for construction of S-curves using each of the 9 individual trends of TESE [4], modified S-curves to detect feature level growth patterns and TESE scores as the numerical evaluators of product states. TESE [4] provides a framework of known progression paths for any technology of interest. Evolution is typified by transitioning from inertial to non-inertial systems, from use of single substance to a mix of substances and fields, and other such modifications with incorporation of additional/available new resources.

TESE captures this essence of increasing ideality wherein the sequential change in a product or process can be envisioned to understand the current design level and also predict the next possible configuration. For each of the 9 trends described [4], a product can be mapped to isolate the particular evolutionary stage to rank the product in terms of its individual and global growth index. It is thus logical to use TESE as a numerical estimator of a product development level. The veracity of our findings is proved by assessing various product parameters of different audio devices – radio, transistor, Walkman, MP3 player and the iPod series. The novel TRIZ methodology of TESE & S-Curve combination is put to practice to highlight each of the enumerated objectives apart from identifying/predicting progressive and disruptive trends in products. However, it is prudent at this juncture to ponder on previous work to fathom MPV's and S-curve building techniques.

Litvin [5] teaches the significance of parameters of value (PVs) and main parameters of value (MPV), and the conditions that differentiate a value from PV to MPV. He further concludes that the MPVs directly connect business challenges to underlying technical problems. Ikovenko [2] states that MPV is the single measure by which a product achieves customer satisfaction. He further employs S-curve analysis to determine the current stage of a given MPV. The gap between actual performance and customer requirements is shown to be a measure of scope, for improving the performance of a product. Cameron [6] discusses TESE and the sub-trend of increasing dynamization in the context of dry-etch tools. The study of evolution of dry etch tools in semiconductor device fabrication indicated an increasing trend of field dynamization, which can further predict the next stage of development. Understanding of evolution trends is thus shown to be a powerful tool to predict future developments in a particular product category. Bush *et al.*[7] posited and correlated the relationship between market trends and TESE. Observations are made demonstrating that evolution trends that interact with the super-system are reflected in market trends while inner processes of evolution perform only a supporting role and are not reflected in the market trends. Kaplan [8] underscored the strong affinity that S-curves have with market, technology and organization strategies, and emphasized how such knowledge can be leveraged to create impactful developments. Sawaguchi [9] established the relationship between the 4 stages of innovation and the S-curve to highlight multiple innovative patterns. Luo [10] used classified innovation *i.e.*, segmentation using the proximity from technology and current customer segment as the two axes of reference, and surmised improvement methods, in alteration and in transient. The conclusion arrived at indicated the need to have the timing of management innovation align with process innovation.

Note that TESE and its incorporation into S-curve construction has however remained largely untouched thus offering huge potential for further investigation. The methodology proposed in this exercise and explained next, exploits this available opportunity to build and perfect TESE scores that are subsequently used to compose S-curves.

2. Methodology & Case Study

The new process being proposed is presented as a sequential heuristic for ease in understanding and greater lucidity, filtering from portfolio to product to features. The methodology is presented along with a *case study* to make it simple to comprehend. The case study involves the domain of audio entertainment with considerable data available regarding a multitude of features. The set of audio devices identified commences with the radio and ends with iPods, spanning pocket transistor, Walkman and Mp3 player in between. Within iPods, multiple generations of the device have been analyzed since the feature set has changed drastically with each offering.

***Step 1 - Identify a product portfolio*:** It is important to select a product portfolio judiciously as all products within that set must have the same main function *i.e.*, the function for which they have been designed for. This compulsion ensures that the scale of comparison is uniform**.** The set of audio devices referred earlier is the product portfolio of interest. Notice that across each of the devices, a useful function, *generate acoustics*, is complied with.

***Step 2 - Identify key features for each product*:** Identify features and cosmetic components or sub-systems for each of the products as suggested in Table 1.

Table 1

List of features

Device Data	**Power**	**Geometry**	**Communication**	**Controls**	**Miscellaneous**
Display	Battery status display	Size	Antenna	Shuffle & repeat	Timeline
Storage space	Electrical connection	Display/ screen aspect ratio	PC connection	Tuning control	Cost
Memory type	# of batteries	Device form factor	Tuning	Volume control	Weight
Volume indicator	Battery voltage	Display		Volume control device	Song selection display
Audio type	Battery type			Power switch	Unique feature
Earphone jack	Battery life				
	Transistor type				

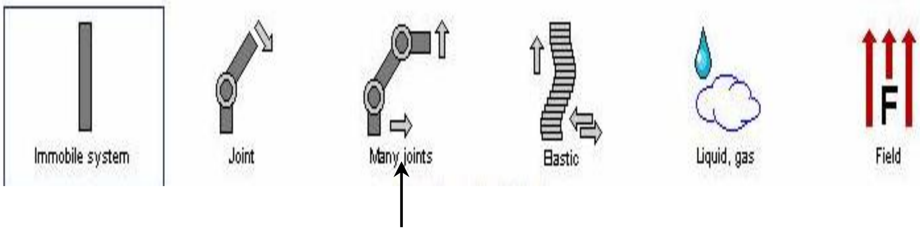
***Step 3 - Dissect each of the products to features level*:** Drill down each product to its bare features and isolate operating modes or mechanisms that involve or affect human interaction. Consider the example of the transistor radio. Notice that some features identified in Table 1 like PC connection, song selection display, memory type, storage space, battery status display etc. are not applicable. Hence, only the relevant features are picked for each device in the portfolio.

***Step 4 - Map each of the features to their respective operating modes*:** For each of the operating modes, identify the corresponding entry in each of the TESE trends. Consider one feature of the transistor radio, the volume control device, which is an integrated power switch and volume knob and is mechanically classified as a **notched wheel** *i.e.*, its operating mode.

***Step 5 - Identify the stage in the particular TESE trend for each of the operating modes mapped*:** For each of the operating modes, identify the stage of development in the particular trend and normalize it to a scale of 1 as explained below:

Trend 1 of the TESE discloses the *Law of System Completeness* [4]. One of the four objects of a complete system is a control unit, which maps on to the notched wheel. Thus, on *trend* 1 the normalized score assigned to the volume control device is 1. *Trend* 2 of the TESE discusses the *Law of Energy Conductivity* [4]. The battery provides source of voltage which is converted to current using resistors. The capacitors are used as filters and the transistors use the current to receive/amplify/alter electro-magnetic waves that are transmitted to the earphones/speakers which in-turn convert them to acoustic waves. Energy conductivity is performed clearly across different sub-systems. Thus, on *trend* 2 the normalized score assigned to the volume control device, as part of the overall system, is 1. *Trend* 3 of the TESE deliberates on the *Law of Part Rhythm Coordination* [4]. All participating components need to be in harmony which is evident in the transistor radio. Thus, on *trend* 3 the normalized score assigned to the volume control device, as part of the overall system, is 1.

Trend 4 of the TESE divulges the *Law of Dynamization* [4]. This specific trend has 6 sub-trends ranging from *immobile system* to *use of fields*. Within this range, the volume control device, mechanically defined as a notched wheel, corresponds to "*many joints*", which is the third generation of evolution. Thus, on *trend* 4 the normalized score assigned to the volume control device is 3/6 (3^rd^ state out of 6 possible states) or 0.5 (see figure below).



Notched wheel = many joints (3rd state out of 6 possible states)
TESE score = 3/6 = 0.5

Trend 5 of the TESE talks about the *Law of Increasing Ideality* [4]. This specific trend has 4 sub-trends ranging from *complete engineering system* to *trimmed system*. Within this range, the volume control device corresponds to *complete engineering system*, which is the first generation of evolution. Thus, on *trend* 5 the normalized score assigned to the volume control device is 1/4 (1st state out of 4 possible states) or 0.25. *Trend* 6 of the TESE discloses the *Law of Super-system Transition* [4]. This specific trend again has 4 sub-trends ranging from *mono system* to *combined poly system*. Within this range, the volume control device corresponds to *mono system*, which is the first generation of evolution. Thus, on *trend* 6 the normalized score assigned to the volume control device is 1/4 (1st state out of 4 possible states) or 0.25.

Trend 7 of the TESE elaborates on the *Law of Part Uneven Development* [4]. Again, this trend exemplifies growth patterns in a device, which has been observed to be uneven. The transistor radio runs on time-limited batteries but has no hindrances in acoustic output. It is quite evident that the power source was not as advanced as the speaker technology at the time. Thus, on *trend* 7 the normalized score assigned to the volume control device is 1. *Trend* 8 of the TESE relates to the *Law of Transition from Macro to Micro Level* [4]. This specific trend again has 5 sub-trends ranging from *monolith* to *use of fields*. Within this range, the volume control device corresponds to *segmented monolith*, which is the second generation of evolution. Thus, on *trend* 8 the normalized score assigned to the volume control device is 2/5 (2^{nd} state out of 5 possible states) or 0.4. *Trend* 9 of the TESE reads the *Law of Increased S-Field Involvement* [4]. This specific trend again has 5 sub-trends ranging from *two objects* to *additive between the objects*. Within this range, the volume control device corresponds to *internal additive*, which is the second generation of evolution. Thus, on *trend* 9 the normalized score assigned to the volume control device is 2/5 (2^{nd} state out of 5 possible states) or 0.4.

Using similar reasoning, TESE scores are established across each of the 9 trends for each of the identified features and their operating modes in each product.

***Step 6 - Average the scores across each trend for each of the operating modes*:** Sum the scores across each trend and normalize it again to a scale of 1 by averaging over the number of operating modes. Combining TESE scores across each of the identified feature and its associated operating mode, we have –

Table 2

TESE scores for each of the 9 trends for TR

Trend	Description	TESE Score
1	Law of System Completeness	1.00
2	Law of Energy Conductivity	1.00
3	Law of Part Rhythm Coordination	1.00
4	Law of Dynamization	0.56
5	Law of Increasing Ideality	0.25
6	Law of Super-system Transition	0.25
7	Law of Part Uneven Development	1.00
8	Law of Transition from Macro to Micro Level	0.47
9	Law of Increased S-Field Involvement	0.42

***Step 7 - Develop the global average*:** Average across all 9 trends to develop the global score for the particular product. Averaging across all 9 trends, the global average TESE score for transistor radio is 0.66 *i.e*., the device is 66% evolved.

***Step 8 - Repeat for each product and plot individual trends*:** Iterate over all products to obtain global TESE indices for each of the products. Repeating the exercise for each of the products listed.

Table 3

TESE scores for all products

Product	Number of	Overall TESE Score

Features		
Radio	6	0.68
Transistor Radio (TR)	11	0.66
Walkman	7	0.67
MP3 Player	12	0.72
iPod Classic	14	0.72
iPod Mini	15	0.72
iPod Shuffle	14	0.72
Pod Nano	16	0.72
iPod Touch	16	0.79

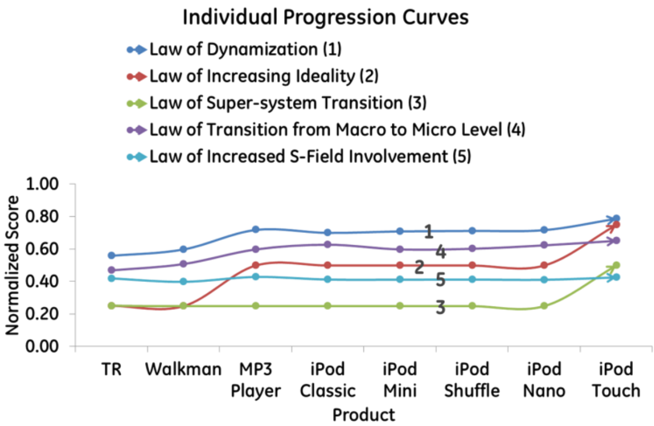


Fig. 2. Individual trends across products

Note that across all mentioned products, Fig. 2, the involvement of S-field is fairly stable. Dynamization and transition from macro to micro level indicate upward growth for iPod Touch, while ideality and super-system transitions have large positive gradients for iPod Touch. Hence, the hypothesis that can be postulated is that iPod Touch is disruptive while all devices preceding it are progressive products. The other four trends are not included in the chart as they assume the same value across all products. Notice also from preceding discussions that TESE has been selected as the basis to construct S-curve, feature level operating modes have been formulated and numerical values of product evolution have been established that are independent of functionality or cost. Note further that the overall TESE score for the transistor radio is lower than that of the radio. This implies that the radio is not part of the portfolio and needs to be eliminated from the set. It is obvious that the rest are all mobile devices while the radio is not. Hence its position as an outlier. This reality check is a trait that is another inherent strength of the process as it can identify potentially incorrect portfolio members. In all subsequent analysis, radio parameters are either discarded are normalized to null values.

***Step 9 - Compare key features across products*:** Contrast the key features isolated from step 2 to develop portfolio growth curves. To recognize key features across products, every feature is compared for each product to observe any dramatic changes occurring over time.

Step 10 - Develop S-curves and correlations: Construct S-curves based on TESE scores from step 7 and comparison metrics from step 9. Identify mathematical correlations, if any, and formulate transfer functions. Plotting the S-curve using TESE scores across products, we have overall TESE scores as shown in Fig. 3.

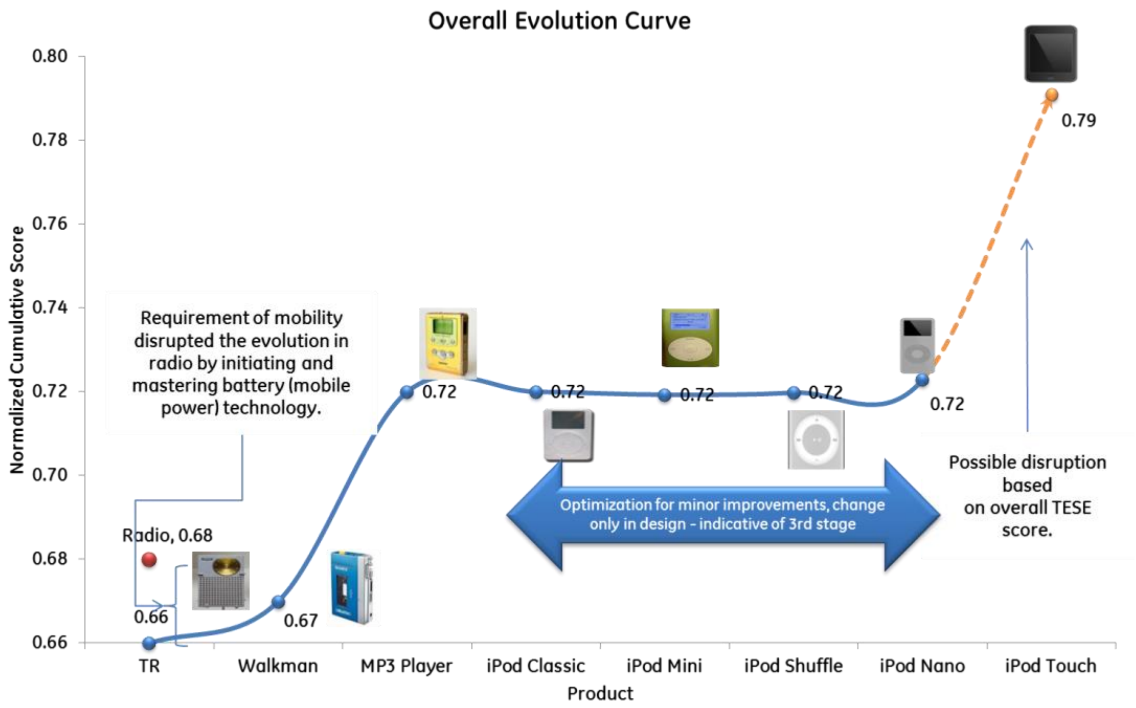


Fig. 3. Overall TESE Scores

Note that steps 1 – 4 provide guidelines to isolate and condition an engineering system for further analysis while steps 5 through 10 generate the numerical understanding of said engineering system in terms of TESE scores. Notice four important observations from the figure above -

a) The S-curve has been built using TESE scores.
b) Radio is not part of the portfolio as its TESE score is contra indicatory.
c) A zone of stagnation has been developed between iPod Classic and iPod Nano indicating that they are functionally similar and are part of the 3rd stage. Intermediate devices included show only changes in design which is suggestive of the 3rd stage.
d) iPod Touch has a TESE score (0.79) that is significantly different from any other product. The hypothesis of iPod Touch being disruptive is validated. All other devices are part of the same S-curve and are hence progressive.

Further lending credence to the disruptive theory, notice from the Table 4 and plot below (Fig. 4), which maps launch dates of each product that iPod Touch is not part of the S-curve constructed. Beginning of the second S-curve for which iPod Touch is the first product lies between iPod Mini and iPod Shuffle, and thus is the first stage of a new S-curve.

Table 4

Products launch dates and normalized indices

Parameter	Radio	TR	Walkman	MP3 Player	iPod Classic	iPod Mini	iPod Shuffle	iPod Nano	iPod Touch

Launch Date	Jan 1, 1908	Nov 1, 1954	Jul 1, 1979	Mar 1, 1998	Oct 23, 2001	Feb 20, 2004	Jan 11, 2005	Sept 7, 2005	Sept 5, 2007
Difference	0	17106	9008	6818	1332	850	326	239	728
Normalized Index	0.00	0.01	0.03	0.04	0.18	0.28	0.73	1.00	0.33

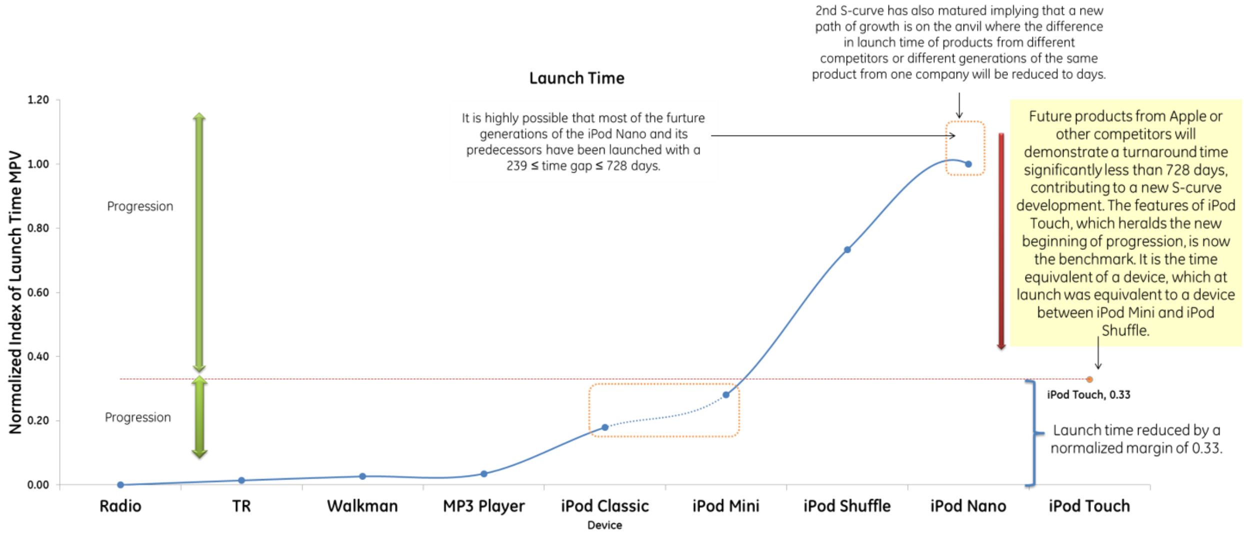


Fig. 4. Product evolution indices in terms of launch dates

Also notice other interesting facets of this plot:

a) There is seamless disruption between iPod Classic and iPod Mini, implying a small set of features of iPod Classic have been improved while retaining the majority architecture of the device.
b) Industry focused on reducing cycle time after the launch of iPod classic, setting off the second S-curve growth. This implies that the features of the iPod Classic had become the minimum acceptable standard and emphasis shifted to mass production.
c) 2nd S-curve has also matured implying that a new path of growth is on the anvil where the difference in launch time of products from different competitors or different generations of the same product from one company will be reduced to days.
d) iPod Touch is the first manifestation of this new S-curve.
e) iPod Touch is a major Disruption, implying a major set of features of iPod Nano have been improved and additional features have been added.

Note that a multi-layer approach has been adopted wherein features are used to assess the appropriate TESE stage, multiple TESE stages are then coupled to obtain the evolutionary score of the product and multiple such products are finally compared to chalk out a growth pattern. Thus, the unit of analysis progresses from a microscopic level to a macroscopic space, spanning features, products and then a portfolio of products.

3. Conclusions

Surmising an extensive investigation, this paper has presented a new form of S-curve construction using numerical values from TESE. Estimation of numerical scores is in itself novel as is the process used to conduct the estimation. Subsequent usage of these values in S-curve development is an innovation brought in by this exercise. Further, innovatively identifying predictive and disruptive trends in an S-curve have been elucidated using the new process. Also, contributions of parameter progression curves have been highlighted to emphasize the rigor and creativity introduced by the process.

Acknowledgements

The authors gratefully acknowledge help and assistance provided by Martha Gardner, Quality Leader, GE Global Research whose support and guidance has been critical for the success of our TRIZ initiatives. The authors also thank MT Shyamsunder, Principal Scientist, GE Global Research for his help in organizing reviews.

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TRIZ*fest* 2015

ONE DAY AT THE MUSEUM – USING A MUSEUM AS RESOURCE FOR TEACHING AND LEARNING TRIZ

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Abstract

This article describes a specific learning experience of ten participants during a MATRIZ Level 3 training program – made in the "Deutsches Museum" in Munich under the mentorship of a TRIZ-master. Besides the introductory background and the empirical description of the experiences of three different learning groups, the article concludes some insights out of this event. These are the base for the formulation of some recommendations and ideas regarding intensification of teaching and learning TRIZ in a museum in future.

Keywords: TRIZ, teaching, learning, innovation, trends, TESE.

1. Introduction: Using a museum as resource for teaching and learning

The experiences described below have been made by adult learners during a MATRIZ Level 3 training. From a pedagogic (or better andragogic) point of view, this kind of learning belongs to the field of further education. Especially in further education the utilization of activating learning settings with strong connection to real world aspects and artefacts is state of the art, see e.g. [1]. Another typical aspect in modern further education is the emphasis on self-organisation within the learning-process – this can be inserted to the learning process e. g. by self-organized tasks that contain full learning circles from knowledge-gathering, structuring of the new knowledge, interpretation, documentation, presentation up to the evaluation of the learning process itself. From a theoretical point of view, TRIZ as learning subject provides optimal junctions for self-organised learning settings – not necessarily in general, but at least as part of TRIZ-education: TRIZ-knowledge is already structured very well, because structuring parameters, principles and solutions is one of the basic achievements of Altshullers works, see e.g. [2],[3]. Furthermore TRIZ-knowledge materializes in form of physical artefacts … and such artefacts can be found in everyday life … and chronologically in a museum.

Most museums consider themselves as source for learning and research. Many museums offer special events or classes for schools and co-operate with universities in research projects, see e.g. [4], [5]. So the idea to use a museum as a learning environment is not new at all. And also in teaching TRIZ the museum is used as a place to learn for many decades. Several TRIZ masters and other TRIZ teachers use museums as a teaching resource for a very long time (see e.g. [6], [7]). Especially the aspect, that the structured and abstract TRIZ knowledge can be identified (or the other way round developed) out of the museums artefacts encourages to use museums more and more to teach TRIZ to others or for self-learning.

2. One day at the Deutsches Museum

As part of the MATRIZ level 3 training course in January 2015 in Munich, Sergeij Ikovenko led the participants to the Deutsches Museum, a big and famous German museum for technology.

2.1. What to learn about?

Before the trip to the museum, the TESE (trends of engineering system evolution) have been discussed in the class. Content of the theoretical sessions has been especially the "hierarchy of trends", as shown in table 1.

Table 1

Hierarchy of trends (according to [8])

<table>
<tr><td colspan="6">Trend of S-curve evolution</td></tr>
<tr><td colspan="6">Trend of increasing value</td></tr>
<tr><td rowspan="3">Transition to the supersystem</td><td>Increasing completeness of system components</td><td colspan="2">Increasing coordination</td><td rowspan="3">Increasing degree of trimming</td><td rowspan="3">Flow enhancement</td></tr>
<tr><td rowspan="2">Decreasing human involvement</td><td>Increasing controlability</td><td rowspan="2">Uneven development of system components</td></tr>
<tr><td>Increasing dynamization</td></tr>
</table>

The course materials provided the structure of the trends, some sub-trends as well as some pragmatic classifications, stages and/or indicators of the trends. The participants gained many insights out of the discussion of the examples that were given in form of pictures or case-studies.

After the discussion of all TESE, the learning goals for the visit in the museum were named: to get a deeper understanding of the trends, to find some evidence for the trends in some artefacts, to identify evolution of technologies over time among some trends.

2.2. How to learn?

To reach the learning goals the following didactical design was used: Teams of 3 or 4 participants should choose one distinct technology or technological area. Each team has about 2 hours to explore its target technology and to identify trends in its history and evolution. After that, each team has to guide the other participants through their insights right at the place in the appropriate area of the museum.

There was no specific form for documentation or presentation demanded – this fits very well with the postulates of self-organized learning. So each team defines its own approach according to its own learning habits and needs. Consequently, each team may have different approaches of reaching the learning goals, different priorities and different structured results, documentations or presentations.

2.3. Team specific learning

The self-organized setting of the exercise allowed different approaches for the teams. In the following chapters 3 to 5 the teams describe their approaches, experiences and insights in their own words.

3. Learning team A: exploring the appearance of trends in printing technology

3.1. Interpretation of the exercise and approach chosen by the team

We decided to visit the printing technology exhibition, and we intended to get an overview by looking through the samples and identify trends when we would spot them.

On our way we walked across the ceramics exposition area – with bricks and other clay work displayed - and we found stamps imprinted in clay bricks by Egyptians and Babylonians. This is a kind of first printing but without using colour, with stamps as a single block but also in form of roller stamps. They are still used today when signing building bricks in brickyards.

Finally we reached the printing technology area we headed for and started the analysis.

3.2. Learning insights of the team

Initially we saw printing as just stamping paper. But after the tour we had a much more generalized view at it as a kind of informing people in a visual way by abstract pictures, symbols or signs. More specific this information is transferred by using a reproduction of the message again and again using a stamp, ink and a carrier for the information i.e. paper.

Printing using ink started only after paper was invented. This reproductive technology is a part of the super system of abstract information transference and in this context could be seen as further completion of the system writing (*Trend of increasing completeness of system components* and *subtrend decreasing of human involvement*).

The *trend of increasing dynamization* gets obvious when we look at the beginning of printing: first there was a block of wood with carved text. Later, when Gutenberg invented movable letters, printing itself became convenient and started to evolve. A line of types was set manually and several lines were composed to a page. This was faster than carving a new block and there was now flexibility to reuse the letters for the next and further pages. Six setters were needed to support one printer therefore the hand typesetting comes to its limits when the newspapers faced larger editions.

According to the *trend of decreasing human involvement* the next steps were machines which could set the letters automatically in line with the help of a keyboard. Afterwards one had just to compose it to pages.

But this technique too had to put a lot of single movable letters into the prepared page frames and was not very fast. The invention of molds (use of copy) instead of single letters allows setting and molding of a complete line in one block. The integration of molding the letters follows the trend of transition to the super system with deeper integration, the *subtrend of decreasing of human involvement* and the *trend of increasing controllability*. But it is interesting that in this case the *trend of dynamization* hat to be reversed (decreasing flexibility from single letters 'back' to one line block).

The evolution followed the *trend of coordination in action* starting with a movable letter (0D) over a line (1D) to a complete page (2D). After continuous paper supply to the printing machine was possible (high paper resource availability) the useful tool function followed further the trend of coordination of action (2D to 3D, the flat printing block was replaced by a printing cylinder).

Regarding realistic reproduction of images, printing technology evolves from relief printing using black/white to surface printing (grey shades), and later to offset printing (4 colors) according to the general *trend of increasing value*. But there is a *trend of uneven development of system* visible as well as we still use paper for all kinds of mass printing.

The trend of *increasing completeness of the system* directed the progression to personal printers. Matrix, ink jet or laser printers followed the *trends of increasing degree of trimming and dynamization* (no more printing letters, deposition of printing ink by field).

What started as sophisticated technology used only by highly specialised experts evolved over time into technology which is applicable by everybody. According to the *trend of transition to the super system with deeper integration* it started with printing of few editions and low spread. High-speed printing machines followed with high output and wider area of distribution. Then rotary printing machines with even higher output in shorter time followed and the development peaked in the home printer where you can create and print your own book on demand. The technical evolution above is accompanied by the growing availability of print media which implies the trend of flow enhancement regarding the spread of information.

According to the trends of *increased controllability*, *increased dynamization* and *decreased human involvement* it even seems most probable that at the end we will use just a display for our e-paper.

3.3. Exercise evaluation of the team

Regarding printing technology we have observed that trends are not like strict laws so they may contradict each other and sometimes they even get reversed to allow the technology to follow a higher trend. Also the main parameters of value change over time – from printing as making a lot of copies to personal printing.

We chose an approach along the historical evolution of printing technology. When we realized that there has been a technological development step we tried to identify the corresponding trend. Sometimes that resulted in the fact that the evolution step could be seen as belonging to different trends. Our learning was intensified and more effective by applying the theory to real and visual objects. Therefore this experience was very interesting, inspiring and highly recommendable.

4. Learning team B: exploring the appearance of trends in drilling

4.1. Interpretation of the exercise and approach chosen by the team

The task for the team was formulated very general: Find examples for the TESE in a specific area of the "Deutsche Museum" and after app. 2 hours, the findings have to be presented. The team decided to select an area which is known very well to almost anybody: drilling machines.

The team started by first purely looking around and recognized very fast an example from a picture in the training course book MA TRIZ Level 3 of this second training week. The *trend of Increasing Degree of Trimming: Sub trend 1 – Trimming Subsystems*. Directly afterwards by guided by the hierarchy of trends we saw the next example at the beginning of the drilling technology approx. 3000 before Christ and identified the *Trend of Increasing Completeness of System Components*. A simple stone wedge as operating agent combined with a bow over a rope, so that the bow can work as transmission. Due to this fast finding the team decided to walk thru the two major rooms in this area and collect for each trend in the course book at least one example to be able to present all the findings to the other teams later. With this decision the session started to become very active and flexible. The team was able to find in the next ten minutes for all the trends in the course book examples. Surprised by this facileness to identify trends the team decided to use the still existing one and half hour to prepare the presentation for the other teams by sorting the examples chronological from the beginning of the technology drilling until the modern time now with a short description of which examples they have found per trend.

4.2. Learning insights of the team

One of the key learnings of the team was the insight, that all the trends exist and that they just never thought about that before the MATRIZ class. The best motivated part from this type of learning was the plainness of identifying all the trends and sub trends. It really stimulates the creativity of the team to think about trends and their appearance with the new challenge to explain some identified examples a huge amount of different trends and subtrends. Also a clarification about the correct separation of different abstract system element appellations, like agents, transmissions or energy sources of different artefacts could be achieved.

4.3. Exercise evaluation of the team

At the beginning of the exercise, from a theoretical point of view, all the trends and also the amount of trends and sub trends in MATRIZ seem to be confusing and complex. With this excursion in the "Deutsches Museum" they became clear and logical. The team came to the conclusion that this visit was a kind of priming of an innovative thinking with trends. This kind of learning by an excursion is very motivating because you can see or feel and even touch the artefacts as examples for the trends. The approach to select a well known area of technology and working with the flexibility of selecting freely different artefacts has made the learning easy. Finally some team members decided still at the end of this exercise to use the same approach of learning inside a company for example with the different production machines in the shop floor of their facilities. With this motivated learning the team finished this interesting excursion to the "Deutsches Museum".

5. Learning team C: exploring the appearance of trends in diving suits

5.1. Interpretation of the exercise and approach chosen by the team

The team selected by gut feeling the division of navigation out of around fifty scientific areas that are presented in the "Deutsches Museum". In this area the temporal evolution of navigation and their branches and everything that goes with it (living and working conditions, ships, design theories, navigation, oceanography…) could be traced in over three floors.

It was the first challenge for the team to focus in this area on a topic, which shows the patterns in technical evolution best. For this it was necessary to find a topic that is presented with many intermediate steps of the temporal development.

To get an overview the team walked through all the different exhibits and discussed them. There were plenty of technological developments that showed the patterns that are described within the theory of TESE. The team decided to start with oceanography and especially diving suits.

In the exhibition, the very first diving suits that were used in the early 17th century were shown up to advanced tank suits that are used for deep diving in the present century.

5.2. Learning insights of the team

After identifying the area of interest the team studied the descriptions of the exhibits in order to be able to identify the Main Parameter of Value (MPV) that drives the technological development of diving suits. The following parameters were found:

- diving depth
- agility of the diving suit
- pressure resistance
- supply of material (e.g. air or communication)
- number of persons (this MPV refers to the transition from a diving suit to diving machines like mini-submarines)

Dependent on the requirements of the particular time different MPVs drove the technological development and in these changes you can find the patterns that are described in the theory of TESE. Below, trends that were found are described for three examples diving google, scuba tanks and diving suits.

Development of diving goggle

The first diving suits had only loop holes in front position of the helmet. Over time the loopholes were adapted to their respective position. A big one in front and smaller ones on the side of the helmet to allow "360 degree" view. In the later development the helmet was trimmed and replaced by the diving google which allow complete 360 degree view.

This example shows the improvement of the MPV *agility* and considers the trends *Transition to the Supersystem*. The TESE of *Transition to the Supersystem* encompasses four sub-trends. For the subtrend *Increasing Differentiation of Parameters* the development of loop holes for diving suits for low depth was considered.

Development of scuba tanks

Starting from simple wooden "barrels" that used the air which was enclosed in it, over diving suits that had an external air supply which pumped air from the surface (boat) via pipes to the diver. In further developments scuba tanks have been the integrated air supply of the diving suit.

Besides *agility* also *supply of material* can be considered as MPV that drove the technological development. Within this example two trends became obvious: the third subtrend of the trend *Transition to the Supersystem,* which describes that the *Level of integration between the Engineering System becomes deeper* like it is for the integrated scuba tanks. But not only this pattern is visible, also the trend of *Increasing Completeness of System Components* fits to this example.

Development of diving suits and diving robots

The first diving suits had the main functions of pressure protection and supply of air. These two functions allowed the diver to work in deep depth and for long time. With the further development of materials the focus went from protection and supply into the direction of agility. With the distinction of materials the MPV *agility* of the diving suits was improved. First diving suits have been made of wood, leather, and glass. Later rubber and metal (e.g. plumber or iron) were also used. Besides the increase of *agility* also the *controllability* increased. For example with sophisticated diving gloves the diver had more freedom to work under water. Later the focus moved from *controllability* to *automation*. Diving robots replaced the diver. Human supporting functions like pressure protection were not needed any longer since the diving robot was more resistant than human. The development of diving suits and diving robots shows the *Trend of Uneven Development of System Components*.

5.3. Exercise evaluation of the team

With this practical exercise in the "Deutsches Museum" it was possible to discover the patterns of the TESE in a very authentic way. By plenty examples the museum supported the exercise like a time travel and showed very vivid that the technological development of systems follows the TESE very often. It showed also that the transition between one trend and another can be very smooth (e.g. development of scuba tanks). Discussions were inspired by the exhibits.

The team deepened and practised the knowledge that was learned in the seminar. For this exercise the team had two hours. Within this time it was very important to focus quickly on a topic since there were plenty of technological developments and all following the theory of TESE. The around fifty areas of the Deutsches Museum give enough material for many more studies of the patterns in the technical evolution and can make a good contribution also in the further development of the TESE.

6. Previous experiences gathered in the museum visit of 2014's class

Public Level 3 trainings have been offered in Austria and Germany several times. The first one took place in December 2008 in Graz, Austria. During this training the group took the chance to visit the Medieval Museum "Zeughaus" for several hours to discuss the development of armors in the middle ages. The next experience exercising TRIZ in a museum was in November 2012 during a Level 3 class in Munich. The participants from Austria (6), Germany (3) and Finland (1) were asked to prepare a museum tour explaining the meaning of the TESE using the 4 topics power machines, aeronautics, mining and telecommunications. The extremely good feedback convinced the organizers that such a trip in the history of technology with real-life examples has to be used as often as possible.

7. Conclusions and perspectives

The conclusions of the participants are not very surprising, but nevertheless very valuable. Using the technical information and the first hand impressions observing the artefacts, the structural knowledge about the trends was consolidated. Furthermore the critical examination of artefacts leaving or interrupting trends supports the reflection of the meaning and use cases of the TESE. So a much more differenced evaluation of the learning content was done by the participants, what especially was fostered by the need, to present their results to the other teams. At the end this need for explication is the most important step of the exercise, to safe the gained new insights.

All of the participants enjoyed this experience and many of them will teach TRIZ later themselves. Using a museum as a learning resource will be part of their teaching arsenal. And there are several other approaches feasible – as well regarding the content, e. g.

- identify the appearance of each inventive principle in just any artefact
- identify the appearance of as much inventive principles as possible in the range of one chosen technology
- similar tasks with inventive standards
- use the cause-effect-chain-analysis to explain, why a specific technology changed dramatically

- use function analysis to create a function model of two different artefacts of the same technology and try to explain the technological evolution step using the models created
- … there are many interesting tasks more to support an intensive learning session

as regarding the didactical design:

- more closed learning settings may contain more detailed task descriptions, forms to fill in, checklists for gathering artefacts as examples etc.
- more self-organized learning settings may support the consolidation of knowledge by even more fuzzy tasks and expectations regarding the results; so e. g. a task after a training session could be: find examples and evidences for your personal top10 learning insights of the class
- preparing learning settings before the class: examine the evolution of a chosen technology and try to identify different stages or changes and document your insights to use it later in the class

So there is a wide field of possibilities to enhance TRIZ education – but just as with any resource: just use it, if it drives you forwards in the direction of ideality.

Acknowledgements

This article and its authors are grateful to all the people that used museums as a resource to learn and teach about TRIZ and technology. They all discovered and utilized this useful source for understanding and knowledge development many years ago and each one developed his or her own procedures and approaches.

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PERSPECTIVES FOR DEVELOPMENT OF AUTOMATED ENTERPRISE MANAGEMENT SYSTEMS

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Abstract

The article describes the evolution and development perspectives of automated enterprise management systems (AEMS) which are currently one of the most important tools of management. Such systems as EDP, MIS, ERP, MRP, APS, MES, OLAP, and CSRP were analyzed. Key contradictions of modern management systems were revealed. Elimination of these contradictions is the moving force of further development of such systems. To perform the analysis TRIZ evolutionary approach is used as an effective tool of knowledge systematization.

Keywords: TRIZ evolutionary approach, AEMS, management, EDP, MIS, ERP, MRP, APS, MES, OLAP, CSRP.

1. Introduction

Constantly growing competition forces executives to look for new methods of management, which allow preserving and expanding an enterprise presence in the market, increasing its profitability. Obviously, the main tasks in addition to traditional associated with the re-equipment, modernization of production and product quality improvement, include rapid response and optimal decision-making, i.e. introducing of an adequate enterprise management system [1]. The role of information technologies was thus an overriding concern. It supports all progressive management innovations. Besides, as a rule, new enterprise management approaches are initially guided by the potential of state-of-the-art IT solutions and have no practical realization without the use of computer systems. In such conditions automated enterprise management systems (AEMS) have become an integral part of the business infrastructure [2]. Thus, it is relevant to analyze AEMS; define the driving forces of such systems evolution and identify perspective directions in their development.

To perform the analysis, the TRIZ evolutionary approach is used [3]. According to TRIZ, artificial systems development is phases alternation of quantitative growth and qualitative leaps. In the process of quantitative growth contradiction appears because of the uneven development of artificial system characteristics. In this case, contradiction can be considered as a manifestation of discrepancies between the different requirements for the system and limitations imposed in it. Identification and analysis of contradictions are the base of forecasting future technologies.

The TRIZ evolutionary approach allows not only organizing and structuring knowledge by means of the TRIZ-evolutionary maps, but also significantly improving efficiency of knowledge accumulation, its representation and studying in the form of systematized blocks. The approach also helps identifying moving forced and development trends of a knowledge field which allow forecasting future ways of ideality increase.

2. TRIZ Evolutionary Approach

In general, the process of the TRIZ evolutionary analysis consists of the following steps.

Step 1 – description of the source object. The source object of TRIZ evolution is a system, which implements the fundamentals of a knowledge field for the first time.

Step 2 – identification of contradictions in this object. Contradictions are moving forces of the evolution; development in the considered knowledge field is performed by the revealed contradiction elimination. The more detailed contradictions are formulated, the more accurate TRIZ evolution analysis will be.

Step 3 – identification of the TRIZ-tools, which helps to resolve identified contradictions. Analysis of TRIZ-tools, which eliminate contradictions at different stages of the knowledge field development, allows identifying main trends of the considered knowledge field development.

Step 4 – description of the following objects, which resolves some contradictions. This step allows defining direction of further development and objects that eliminate revealed contradictions, if there is contradictions elimination.

Then, steps 2-4 are repeated for all the most significant object of the knowledge field with a desired degree of detailization.

Step 5 – construction and analysis of the TRIZ-evolutionary map. The TRIZ evolutionary map is a scheme, elements of which are objects of TRIZ evolution; TRIZ-tools, which provide a transition to the next stages; connections between objects, shown by arrows. Each arrow is an iteration of the TRIZ evolution. Iteration can be also defined as a transition from an object to the group of objects of TRIZ evolution.

Effectiveness of the approach in systematization of knowledge and analysis of artificial systems evolution trends was submitted by researches of programming paradigms [4], CASE systems [5] and other knowledge fields.

2. Characteristics of Production Management

Managing a modern manufacture includes a large number of general and specific tasks at different levels, from the management of equipment to the control of financial flows. Manageability is one of the most important criteria for any enterprise working in a dynamic market environment.

There are three management levels: strategic, tactical and operational [6].

Strategic level. Strategic management is a set of principles, forms, methods, techniques and tools of management based on long-term forecasting, comparing of internal and external factors; accounting resource limitations; and system of strategic objectives which are criterion for management decision making [7].

Tactical level. At this level manufacturing schedule is prepared on the basis of production plan based on more detailed information on the production facilities. Manufacturing schedule describes a sequence and duration of operations at work centers over the planning period; defines detailed strategies and constituent activities to the level of operations for the period of 1-3 years; performs planning of production capacity, marketing, capital, personnel and investment [8].

Operational level. Since many stages of the real production process are not considered or properly described at the tactical management level, operational management is required to adjust and refine decisions made at the tactical level to meet changing conditions of a real production process. The result of planning at this level is the set of shift-day tasks.

General information about management levels is described in the table 1.

Table 1

Management levels

Indicator	Strategic Level (S)	Tactical Level (T)	Operational Level (O)
Management object	Enterprise	Producing department	Work center
Object of focus	External environment	Production resources	Manufacturing schedule
Time	Long-term	Mid-term	Short-term
Effectiveness criteria	Expediency and accuracy of the enterprise response to the new demands of the market with a focus on profits	Rationality of production resources use	Regularity of pace, uniformity and timeliness of plan fulfillment

The enterprise's success depends on the speed and efficiency of decision making at each management level. Information and management structure of manufacturing plant includes components and subsystems which allow automating management on different levels.

3. Evolution of AEMS

3.1 Types of AEMS

The article considers the most significant types of AEMS, such as EDP, MIS, ERP, MRP, APS, MES, OLAP, CSRP and IAMS. Brief description of all systems to be considered and analyzed is represented in Table 2.

Table 2

Automated Enterprise Management Systems

Name	Description	Management Levels Supported
EDP	Electronic data processing	Operational
MIS	Manufacturing information system	Operational
MRP	Material requirements planning	Tactical
OLAP	Online analytical processing	Tactical
MRP with closed loop	Material Requirements Planning systems with closed loop	Tactical
MRP II	Material requirements planning II	Tactical
ERP	Enterprise resource planning	Tactical
APS	Advanced planning and scheduling	Tactical, Operational
MES	Manufacturing execution system	Operational
ERP II	Enterprise resource planning II	Strategic, Tactical
CSRP	Customer synchronized resource planning	Strategic, Tactical, Operational
IAMS	Integrated automated management systems	Strategic, Tactical, Operational

Further, let's consider the TRIZ evolution of described AEMS.

3.2 The source object of TRIZ evolution (EDP systems)

Up to 60s of XX century, the main function of information systems has been simple: interactive query processing, record storage, accounting, etc. Systems for performing these operations can be defined as electronic data processing systems (EDP systems). EDP-system can be considered as the source object of TRIZ evolution.

Until 1965 the development of large information systems was not only technically challenging but also very expensive. Development of IBM System 360 available for corporate use has led to greatly increased demand for processing an increasing volume of information; external environment required from by enterprises a rapid response to changing conditions [9]. EDP-system allowed to efficiently process and store information, but to make effective management decisions it was required to structure and analyze it. Often, it took a lot of time. Thus *contradiction 1* revealed: with increasing volume of information to be process time for decision making unacceptably increase.

The contradiction was eliminated at the following iteration of TRIZ evolution. The first MIS systems were created.

3.3 MIS systems

Contradiction 1 was partly eliminated using the Principle of Merging by introducing a uniform data model across the organization and modules for report compilation based on different categories of indicators.

The first MIS systems developed in the mid 60s were focused on providing executives at the operational management level with structured and regular reports required for making decisions [9]. Reports were being compiled on the basis of data from information reporting modules. Most of this information was taken mainly from data processing and accounting.

Thus, the first iteration of AEMS TRIZ evolution performed (see fig. 1).

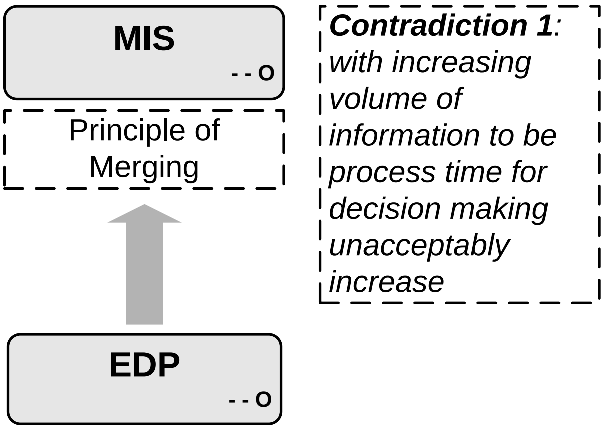

Fig.1. First iteration of AEMS TRIZ evolution

MIS systems also had series of restrictions. For example, rigidly structured results of reporting systems no longer meet the requirements of management. MIS systems could not provide specialized, interactive support and decision-making in the unique conditions of a rapidly changing environment. Thus, there is a *contradiction 2*: with increasing scale of enterprise operating conditions dynamic the efficiency of systems unacceptably decreases.

Besides, at the end of the 60s enterprises with lots of automation-equipped working places looked for a way to simplify the management of production processes. *Contradiction 3*: with increasing number of automation-equipped working places complexity of management unacceptably increases.

Development of management methods identified the need to automate more complex tasks and complex processes. For example, it was found that the most part of production delays are associated with delay of individual components providing. As a result, with the decrease in production efficiency, there is excess of materials received on time or ahead of schedule. Besides, due to an imbalance of components supply, there are additional complications with monitoring the status of a production process, i.e. it is virtually impossible to identify which party a constituent element belongs.

Existing MIS systems did not provide enough functionality for the management of process planning and resource allocation. Thus, there are contradictions 4 and 5. *Contradiction 4*: with increasing complexity of the management tasks associated with production planning, efficiency of the system unacceptable reduces. *Contradiction 5*: with the use of the system at the tactical and strategic management levels, management efficiency unacceptably reduces.

Contradictions 2, 3, 4, 5 were eliminated in OLAP and MRP systems.

3.4 MRP systems and other AEMS

MRP systems allowed eliminating contradiction 3, 4 and 5 by the principles of "Local quality", "Segmentation" and "Dynamics". Tasks associated with production planning were taken into the system of automated control at the tactical management level. These systems are directly specialized for the tasks of manufacturing resource planning. The MRP system accelerates the delivery of the materials that are currently needed and delays the premature deliveries, so that all components from the list of complete components kit of the final product are delivered to work center at the same time [10].

Thus the second iteration of TRIZ evolution performed (see fig. 2).

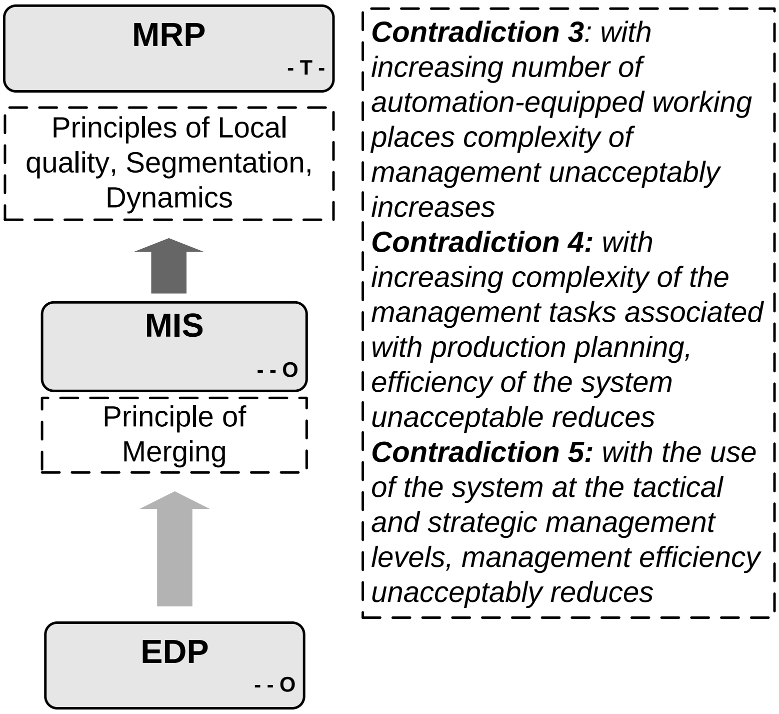

Fig. 2. Second iteration of AEMS TRIZ evolution

Systems that work on the MRP methodology allow optimally adjusting deliveries of components to the production process, controlling stocks and production technology, reducing production costs and increasing its efficiency. However, this methodology has a number of disadvantages:

- A significant amount of computing and data pre-processing increases the risk of crashes and system problems (*contradiction 6*: with increasing amount of computing and data pre-processing fail-safe feature of the system unacceptably worsen);

- Inability to update the final information obtained during the system work, i.e. to adjust to the changes that occur in open orders. There is a lack of tools to respond changes in demand after calculating the final plan (*contradiction 7*: when changes of the source data are made after the final manufacturing schedule calculation efficiency of the system unacceptably decreases).

The following objects of the AEMS TRIZ evolution were considered in the same way. The complete TRIZ evolutionary map of AEMS is represented in figure 3.

3.5 Analysis of the AEMS TRIZ evolutionary map

Analysis of the AEMS TRIZ evolutionary map shows:

1) There are 4 stages of AEMS evolution: 1 – EDP systems; 2 – MRP systems; 3 – ERP systems; 4 – Integrated automated management systems (IAMS).
2) Main moving forces of AEMS evolution are principles of local quality, and dynamics. The principle of "Local quality" has influenced the development of a wide set of sub-systems and components that are used within the AEMS to settle specific management tasks, such as supply chain management, etc. About 44 subsystems were defined during analysis. The Principle of "Dynamics" has influenced the flexibility and efficiency of AEMS in varying operating conditions under the influence of external and internal environment.
3) The evolution of AEMS as artificial systems corresponds to the trend of transition to the super-system. Thus, the systems created at the initial stages of evolution subsequently incorporated into a later generation of systems as components or subsystems.
4) The evolution of AEMS as artificial systems corresponds to the trend of enlargement and trimming. The most significant enlargement of AEMS occurred at the stage of ERP systems development, but the next stage shows the tendency of trimming. The last stage of AEMS evolution is characterized by a tendency to merge into a single integrated automated management system (IAMS) based on technical hardware and special software that covers all management levels, including the production process management level. Such systems have a number of disadvantages. Many of them connected with implementation of the system in real conditions, because it requires introducing new technologies; staff training and supporting system at all levels. There is a *contradiction*: with increasing efficiency of production management (as a result of IAMS implementation), time for staff training adaptation to new technologies unacceptably increases.

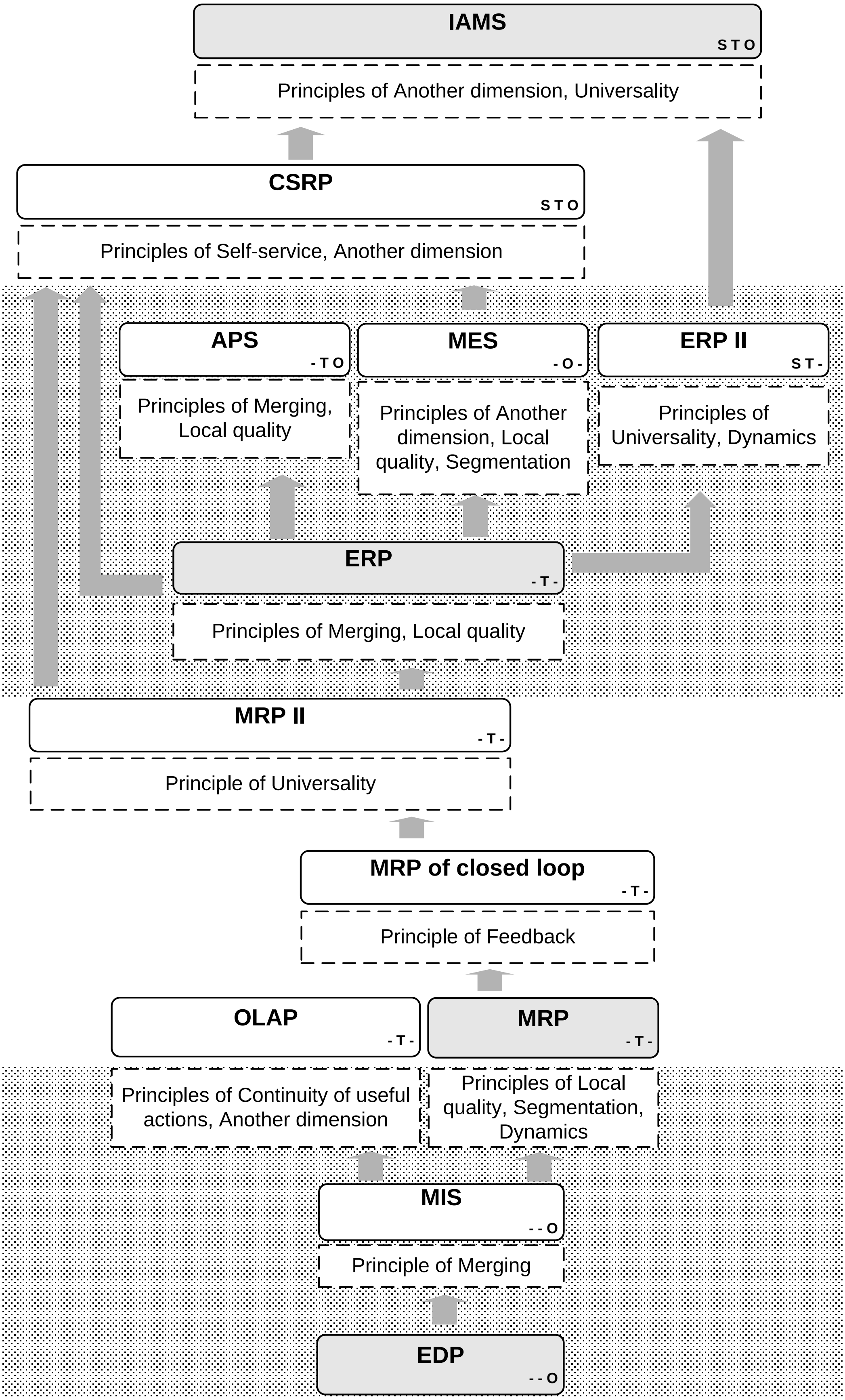

Fig. 3. TRIZ evolutionary map of AEMS

4. Discussions and Conclusions

The revealed contradiction can be eliminated using the principle of Intermediary by implementation of expert systems at the level of production process management.

Such expert systems could provide the following functionality [11]:

- Ability to accumulate knowledge and update it basing on an active analysis of technological information, including generalized experience of the design technology and results of technological researches.
- Ability to react and provide a variety of solutions for a number of tasks basing on the accumulated knowledge.
- Ability to learn and describe the process of decision making.

Expert systems should be integrated with hardware and software complex at the level of production process management. Such integration could simplify the process of staff training and provide a number of tools for effective decision making on the base of accumulated knowledge.

The suggested solution is supposed to be analyzed by authors in more details and be tested and proved in real conditions.

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PRACTICE FOR SOLVING PROBLEMS AND GENERATING NEW CONCEPTS BASED ON TRIZ-DAGEV ROADMAP

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Abstract

A creative solution for most problems of administration, TRIZ has been used for creating ideas and solutions in various fields of R&D. However, there are some issues regarding using TRIZ in terms of its effectiveness and efficiency. For example, although TRIZ offers many thinking tools, users have reported that they used only a few tools to develop a solution or new concept. In addition, some users do not properly understand the TRIZ thinking process even after taking learning courses for more than 40 hours.

This paper aims to review some issues regarding the use of TRIZ and present a brief analysis of how TRIZ tools have been used in real practice. For this review and analysis 198 projects were screened. The majority of those projects have led to new patents and ideas. In addition, all of the projects were classified as having two groups: problem solving and new concept generation.

For the research, data collection was done through an assignment report based on a TRIZ-DAGEV roadmap (DAGEV stands for Define, Analyse, Generate, Evaluate, and Verify). TRIZ-DAGEV roadmap was predetermined process based on ARIZ. Through the TRIZ-DAGEV template, the information concerning the frequency of use of TRIZ tools was collected from TRIZ users, from which then TRIZ experts evaluated the user's understanding of the TRIZ tools by an oral examination.

The main results of this research are as follows. First, TRIZ users are mainly applying easy tools, such as the inventive principles and contradiction matrix to solve their problems and generate ideas. But the better ideas, the much more tools were used in TRIZ projects. For generating new concepts, TRIZ users prefer to use idea generation methods such as FOS rather than problem analysis tools such as multi-screen thinking or function analysis. Second, most TRIZ users responded that it is easy and useful for them to apply TRIZ-DAGEV roadmap and TRIZ tools for their R&D projects. However, there are still some users those who mentioned that TRIZ process is complicated and difficult. Finally, TRIZ experts have stated that some users have used TRIZ methodology, not by an inductive thinking process, but by a deductive thinking tool.

Keywords: TRIZ, TRIZ-DAGEV roadmap, Problem Solving, New Concept Generation

1. Introduction

TRIZ was developed mainly for technical problems. It has been also applied in various other fields, including the new product developments, technology forecasting and so on. Although

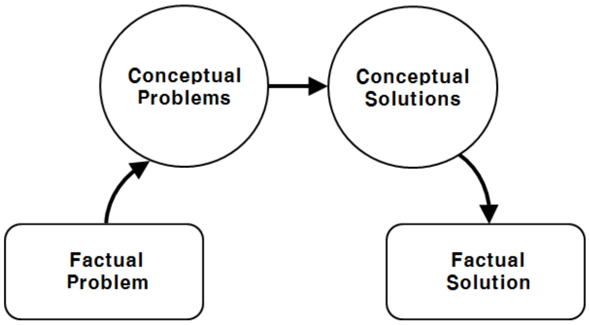

Fig. 1. TRIZ approach to problem solving (Gadd 2011)

TRIZ methodology has been regarded as a useful thinking tool for problem solving, there are practical issues which are related with difficulties of use.

TRIZ is a systematic approach of inventive problem solving and it can be explained in conceptual format. In its conceptual form, the problem can then be matched with one or more of the conceptual solutions. The identified conceptual solution can afterwards be transformed into a specific, factual solution that addresses the original factual problem. This approach is the overview of the TRIZ problems solving process (Savransky, 2000) [1]. Gadd(2011) also noted that the TRIZ methodology provides a considerable advantage to identify problems and offers direct solutions to them. The TRIZ problem solving process is a systematic approach to explore specific factual solutions to factual problems (Fig.1) [2]

As well as Darrell Mann described a hierarchical perspective of TRIZ as a pyramid structured picture (see Fig. 2). At the bottom of the TRIZ hierarchy, there are wide-ranging and comprehensive series of tools and techniques. The tools contain a great deal level of richness. To all intents and purposes, it may be said that there is a tool for practically any problem that may be encountered. (Darrell Mann)[3]

So, TRIZ offers a large number of techniques and methods including Inventive Principles, Standard Solutions, Trends of Evolution of technical systems, Separation principles and so on.

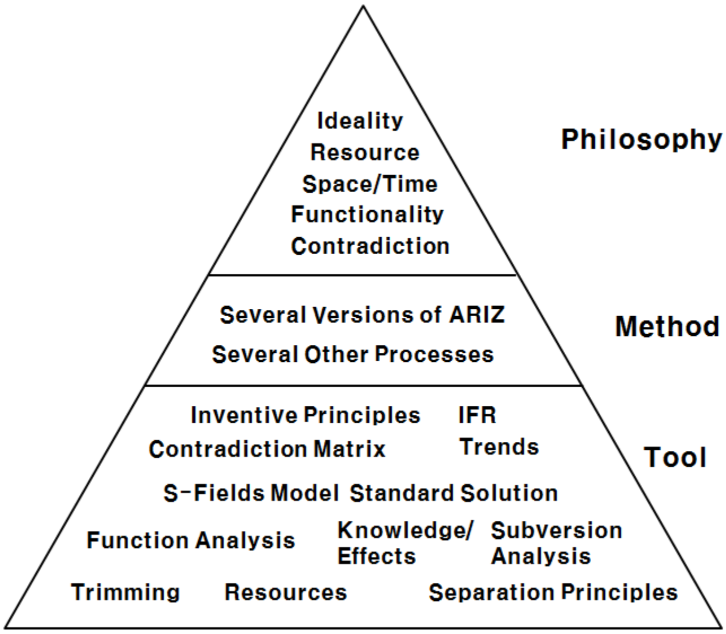

Fig. 2. Hierarchical View of TRIZ (adapted from Darrell Mann,"Who Will Learn and Use TRIZ"(www.triz-journal.com))

However, it is not easy for TRIZ beginners and learners to understand such a huge set of tools and knowledge bases.(Nakagawa, 2002)[4]. As shown in Fig. 2, the learners understand that the TRIZ tools are mixed with complexity, regardless of the characteristics of TRIZ tools.

In other words, they don't know which tool is right to analyse problems and generate solutions. Throughout the mention of Eversheim that the TRIZ methodology does not provide a strict sequence or specific procedure in the application of the tools, we can find out the reason why the learner doesn't know how to use TRIZ in practice. (Eversheim, 2009)[5]

There are two suggestions that they classified tools to clear the confusion of mixed set of tools depending on the application of TRIZ. Zlotin et al. (2000) provided three groups of TRIZ tools: analytical tools, knowledge-based tools and psychological operators. Analytical tools include such as Su-field analysis, functional analysis, and ARIZ, while the knowledge-based tools are inventive principles, standard solutions and effects.[6] The last group, the psychological operators is useful to facilitate the creative and problem solving process. By considering the importance of problem analysing and solving, Moehrle (2005) suggested a frame work to structure the TRIZ tools.[7]

So, we can make the bottom of Hierarchical view of TRIZ clearer than Darrell Mann's suggestion based on previous TRIZ literatures as shown above. (Fig.3)

As mentioned above, it is necessary that the process of TRIZ is structured simply and clearly. This paper is concerning the qualitative exploration to evaluate the process of TRIZ method.

In this paper, TRIZ is reviewed as a tool for two purposes. One is for solving problems of existing technical system and the other is concerning the new concept generation for innovative products. A section of Data Collection is focused on examining the experiences of people who have actually applied TRIZ in SAMSUNG. These experiences are gathered from the final reports of TRIZ projects. The benefits they gained and challenges they faced while applying TRIZ are pointed out making that more informative than any other conventional TRIZ literature.

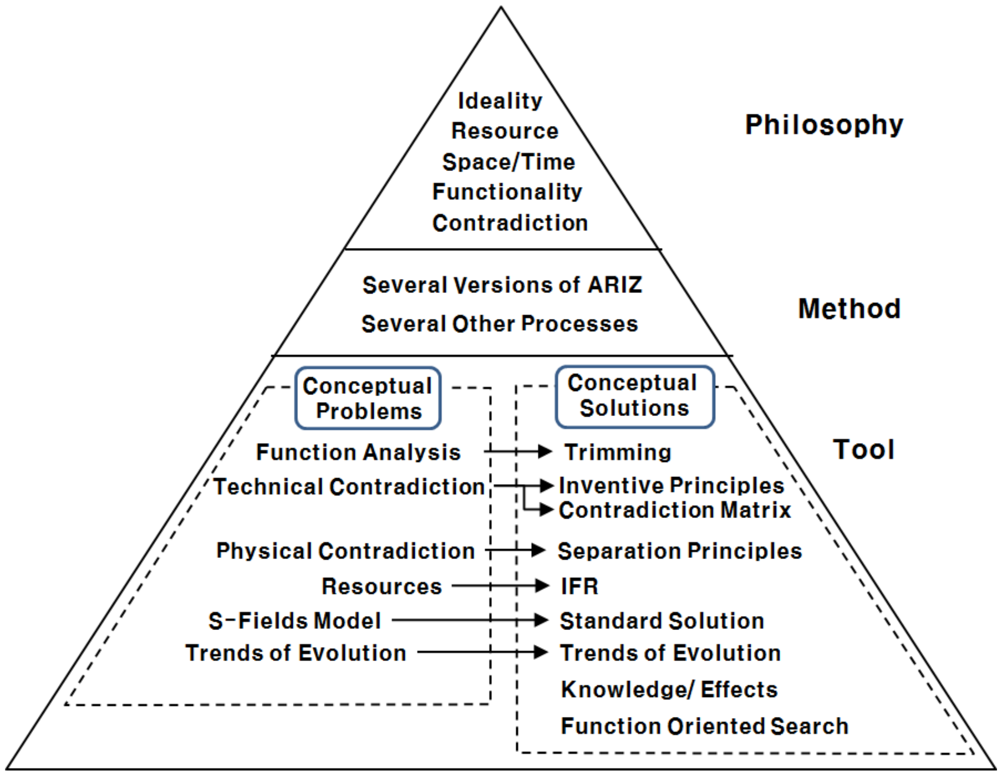

Fig. 2. Hierarchical View of TRIZ based on problems & solutions

2. Design of TRIZ Roadmap

TRIZ Roadmap is designed for using TRIZ tools practically according to the process to carry out projects. As well as it is made up for guaranteeing clarity and simplicity of the process of TRIZ project which is essential requirement when TRIZ Learners apply TRIZ tools.

The Project reports in this study are predetermined as TRIZ Roadmap that is basically composed of 5 steps such as Define, Analyze, Generate, Evaluate, and Verify. The 5 step process, DAGEV road map is standardized for raising clarity of the process of using TRIZ tools.

The types of each TRIZ projects are classified as Problem Solving and New Concept Generation according to the objective of the project and the optimal TRIZ tools. And the 5 step process is structured for each types of the TRIZ project. Thus, the TRIZ-DAGEV roadmaps are also classified into two types. The TRIZ-DAGEV Roadmap for Problem Solving is designed based on ARIZ and results of successful TRIZ projects performed in Samsung Electronics, and the TRIZ-DAGEV Roadmap for New Concept Generation is made up of the definition of hidden needs, laws of technological evolution, FOS (Function Oriented Search), etc. In case of new concept generation, the DAGEV road map is focused on idea generation.

2.1. TRIZ-DAGEV Roadmap for Problem Solving

The TRIZ-DAGEV Roadmap for Problem Solving is fundamentally based on ARIZ 85-C. In Analyze Step, analytical tools which are not included in ARIZ 85-c, such as Root Cause Analysis, Function Analysis, etc. are newly added. In Generate Step various idea are generated generated according to the divergent thinking skill of ARIZ 85-c. In Evaluate and

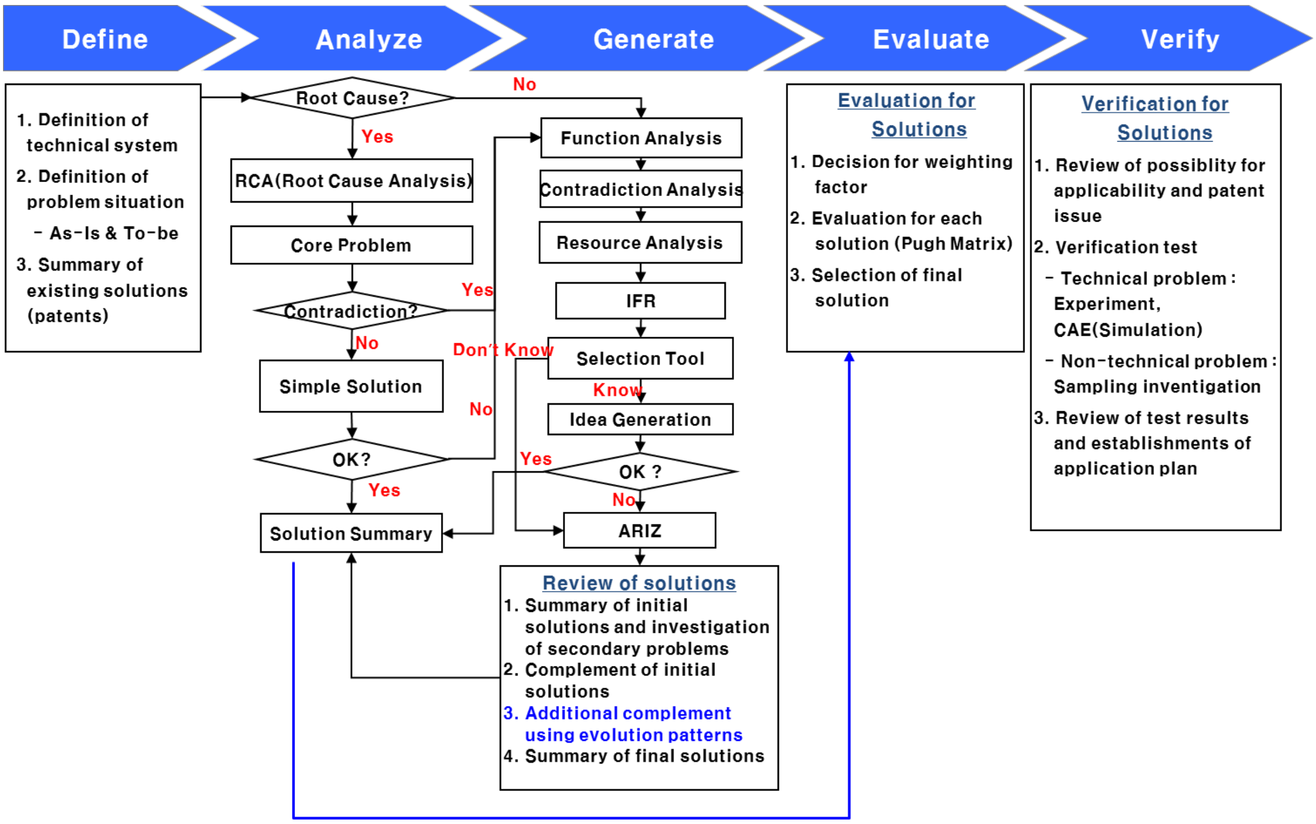

Fig. 3. TRIZ Road map of Problem Solving (SAMSUNG Electronics TRIZ Manual, 2015)

Verify Steps, using categorization, selection and implementation process, various ideas are merged to implementable creative idea.

2.2. TRIZ-DAGEV Roadmap for New Concept Generation

The TRIZ Roadmap of New Concept Generation for innovative new product is made by analyzing results of three key researches using TRIZ technological prediction methodologies.

The Evolution Potential map proposed by Darrell Mann is useful to base decisions on R&D strategy because it can intuitively detect the current status of evolution in a technical system. [8] However, there are some variations in the evaluation results of the technical system by the specialty of each evaluators, and as one of main momentum of evolutions, external environments such as society, economy, strategy, etc. do not considered in evaluation.

The TRIZ-DE (Directed Evolution) methodology proposed by Boris Zlotin and Alla Zusman has an assumption that the technical system has specific direction limited on clear intent and purpose when the technical system is evolved. Thus, it gives clear solution of ambiguity when

8 laws of evolution of technical system proposed by Altshuller. [9] However, the ambiguity of selection criterions on laws of evolutions and time gap between events in timelines of the technical system can deteriorate the usability of the TRIZ-DE methodology.

Table 1

Characteristics of TRIZ-DAGEV Roadmap for New Concept Generation

Prior Research	**Positive (Negative)**	**Usefulness for roadmap**
Evolution Potential Map	Easy to detect current status (No consideration for external environments)	Application for generating ideas, not for analyzing current status
TRIZ-DE	Versatility for systematic process (Arbitrary interpretation → Lack of objectivity)	Establishment of standard process into 5 steps(definition, analysis, idea generation, evaluation, verification)
MST & TRIZ-DE	Intuitive detection based on time-space domain (Needs for too much data for analyzing super system)	Minimization for analyzing super system (Focusing on core function and performance of technical system)

H. S. Yeo has introduced case studies of technical predictions using Multi Screen Thinking method and 42 evolution lines in TRIZ-DE methodology. He extends the existed Multi Screen Thinking into time-space domain and accepts momentum from external environment as super-systems. So, in his case study, the correctness of timing of technical evolution became better but the scope of the project is too big to apply short-term project. Therefore, we consider not only the maximum simplicity in effect but also prevention of damage to reliability in efficiency. [10]

Table 1 shows requirements for the TRIZ Roadmap which are found out after we analyzed three previous researches' strengths and weakness. Based on these requirements, the TRIZ Roadmap for New Concept Generation was designed as shown in Fig. 5. [11] Besides, we referenced to Design Thinking as a well-known user-oriented toolkit and adopt User's Hidden Need table to find user's requirements in detail. We also included concretization of simple solutions, Contradiction analysis of expected problems when the simple solution is implemented.

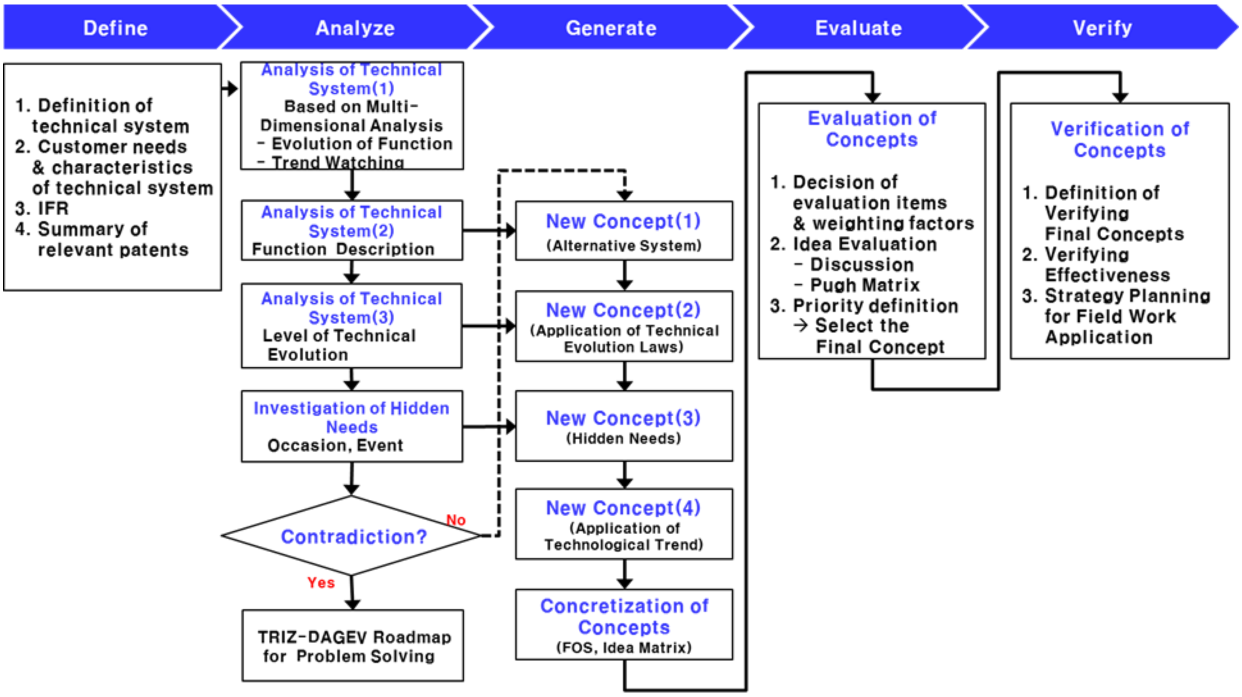

Fig. 4. TRIZ Road map of New Concept Generation (SAMSUNG Electronics TRIZ Manual)

3. Data Collection and Analysis

In this research, as basic data, we used 198 TRIZ project reports which have been presented from March to October 2014 by 99 engineers who took more than 100 hours' TRIZ training Course by the regular curriculum in Samsung Electronics.

In Samsung Electronics, regular education curriculum comprises categorized Basic, Intermediate and Advanced level. Project reports used in this research are results from Advanced level course. Also, the Quality of each project was proved by patent application or application on field-work.

Most respondents mentioned that TRIZ-DAGEV roadmap helps to identify and clarify problems and makes it easy to approach the projects systematically. But, there was a very small number of TRIZ users those who still felt it was complicated to understand TRIZ process.

Over 98 engineers, 68 engineers carried out 156 projects for Problem Solving and 30 engineers carried out 42 projects for New Concept Generation. Each project has reviewed by the review committee whose members have at least MATRIZ Level 3 certification. In reviewing, all the projects are categorized into excellent project group and re-deliberative project group by criterions such as appropriateness of project selection, understanding of TRIZ methodology, novelty of solution idea, ripple effects by the result of the project and etc. The results of projects are summarized in Tables 2 and 3.

3.1. The results of Problem Solving Project

The results and performance associated with R&D projects using TRIZ-DAGEV road map was gathered from TRIZ reports as followed (see Table 2). When it comes to performance, a number of patent applications is much bigger than Idea Application on field work. However, a number of patent applications of Group B is lower than Idea Application of field work, which can be explained by the level of idea. Most ideas of Group B are regarding the conceptual design or some kinds of know-how. If the know-how is organized into project performance, project reports showed the characteristic to take advantage of the TRIZ tools in pieces.

Table 2

Result of R&D Project using Problem Solving Roadmap

Performance / Group	Number of Projects	Performance (ea)	
		Patent Application	Idea Application on field work
Group A (Excellent)	97	151	48
Group B (re-deliberative)	59	24	38
Sum	156	176	86

3.2. The results of New Concept Generation Project

Table 3 shows the results and achievements of the performance of TRIZ projects for the New Concept Generation challenge. Compared with the case of Problem Solving, the number of Idea Application on field work is more than twice than the number of Patent Application. This is just because the level of idea for New Concept Generation projects is close to the early-stage of new product. So, in order to apply the patent by using these types of results, it is necessary to further work that can be verifying the possibility of implementation of the idea.

The TRIZ project using TRIZ-DAGEV Roadmap for New Concept Generation has several features in Analysis and Generate Step as follows;

First, the usage of MST (Multi Screen Thinking) in Analysis Step is more dependent on design-oriented disruptive innovation in market point of view not on usual technology-oriented sustaining innovation;

Table 3

Result of R&D Project using New Concept Development Roadmap

Performance / Group	Number of Projects	Performance (ea)		
		Patent Application	Patent Pending	Idea Application on field work
A Group (Excellent)	15	3	7	12
B Group (re-deliberative)	27	2	-	21
Sum	42	5	7	33

Second, Evaluation of current status of technical system based laws of technological evolution in Analysis step tend to use as an idea generation tool not as an analysis tool;

Third, the most useful tools in Analysis and Generate Step are arranged Event Analysis for detect user's hidden needs, Occasion Analysis, Observation of technological trends using searched data and FOS in order;

Fourth, people in the project generate more novel idea when they use TRIZ tools with complementary and general manner than when they use each TRIZ tools independently.

4. Discussion and Limitation

4.1. Discussion

R&D projects experienced with TRIZ include difficulty associated with its learning and application. In order to decrease or mitigate these difficulties, TRIZ tools, including Inventive Principles, Standard Solutions, Trends of Evolution, Separation Principles, etc., have been structured in this study as a TRIZ-DAGEV road map.

Most TRIZ users depicted that a full understanding of TRIZ requires substantial investment in time and resources, due to its extensive scope and various kind of thinking tools. However, the well-defined structured roadmap could help to make it easy to approach the core of problems. The standard thinking process such as TRIZ-DAGEV roadmap is very useful to understand the TRIZ process and provide a framework to analysing the problems and generating some ideas when used in practice.

4.2. Limitation of this study

When a result of project such as a patent is pending progress or planned to field work application, the data of performance contains an ambiguity which cannot be clearly aggregated. Since the research was followed up by analysing the TRIZ DAGEV reports, there is a limitation that we cannot analyse and measure statistically the opinion of TRIZ users. And it is difficult for this study to be generalized, just because the results of this study are concerning some cases of the specific company. Therefore, to generalize the effectiveness of TRIZ-DAGEV roadmap, it would be required that more and more sophisticated discussions and jobs including many types of problems and cases are included.

5. Conclusion

The main results of this research can be summarized in three major points.

First, the better ideas are, the much more TRIZ tools are utilized in practice. For generating new concepts, TRIZ users prefer to use idea generation methods such as FOS, than problem analysis tools such as multi-screen thinking or function analysis. Especially, they are mainly applying easy tools, such as the Exploration of hidden needs and contradiction matrix, to find out the innovative new concept of products.

Second, most TRIZ experts responded that it is easy and useful for TRIZ users to apply TRIZ-DAGEV roadmap and TRIZ tools for their R&D projects. However, there is a small number of users those who still mentioned that TRIZ process is complicated and difficult.

Finally, TRIZ experts have stated that some users have used TRIZ methodology, not by an inductive thinking process, but by a deductive thinking tool.

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TRIZ*fest* 2015

REDESIGNING THE WAY FUTURE ENGINEERS LEARN TO SOLVE INVENTIVE PROBLEMS

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Abstract

The potential interplay between design thinking and TRIZ motivated engineering educators to redesign the inventive problem solving experience for future engineers. The rationale of using design thinking as a research methodology is its revolutionizing and iterative nature. It encourages researchers to craft superior elucidations by learning from initial mistakes that make sense to them and its interactive processes to approach complex problems, collaborate with innovation, create holistic and sustainable solutions through a human-centered lens. The complex problem of promoting and integrating design thinking with TRIZ for future engineers demanded the fusion of various perspectives and the knowledge of engineering practice and education. The design thinking processes allowed us to effectively channel the potential of interdisciplinary and transdisciplinary collaboration by creating a shared problem awareness and establishing a common language to address the workplace demands. Guided by the design thinking methodology, the authors collaborated to design the interactive process of inventive problem solving through inductive teaching and learning methods for continuous improvement in engineering education.

Keywords: Design Thinking; TRIZ; Engineering Education; Inductive Teaching and learning; Continuous Improvement.

1. Motivation /State of the Art

Creativity and innovation along with sustainable, dynamic, and healthy living are in growing demand despite of all the challenges of 21st century. For the futuristic needs, we depend on brains who are engineers and scientists. From embedded technology of household appliances to high-speed microprocessors and micro-controllers in smart phones, from a minor disease to deadly cancers, we look forward to the technological advancements. Electrification, automobiles, airplanes, water supply and distribution, electronics, radios and televisions, agricultural mechanizations, computers, telephones, refrigeration and air conditioning, internet, highways, imaging, household appliances, spacecraft, health related technologies, petrochemical technologies and petroleum, fiber optics and laser, nuclear based technologies and high-performance materials are selected examples of the greatest engineering achievements of the 20th Century (Mahmood et al. 2013).

The structural disproportion between today's need of the world, and the production of, engineers and scientists, along with the risks and uncertainties of counting on imported and foreign talent, should be given real attention. There is an utter need to address the problem of producing a workforce locally that consists of capable engineers and scientists who will be equipped to face the global challenges of the new century (Mahmood et al. 2013). Rover (2008) highlighted the competence-based approach in "Global Engineering Excellence" report and stated global engineer as generally knowledgeable, professionally competent, innovative and entrepreneurial, culturally flexible, market savvy, well versed about world market demands, professionally adjustable, adaptable and mobile. A global competent engineer (Downey et al. 2006) should also be knowledgeable, positively inclined towards professionally different opinions related to problems in hand and ready to learn from local as well as international expertise, equipped with the ability to analyze the way people live and practice around the globe, biased to deal with the diversity of people's perception about problems and their solution (Downey et al. 2006).

Keeping in view the wide-ranging challenges faced by engineers like the ever-increasing rate of technological developments and advancements, the emerging innovations in new fields, the expected population shifts to progressing areas of the worlds and the evolving need of integrated technology in our daily lives, it is vital for engineering education to deal with these challenges effectively. Furthermore, "the importance of technology in health care, public policy, national security, and business will require that engineers have a variety of professional aptitudes in addition to technical proficiency" and "the scope and nature of the challenges facing engineering education make it critical that our directed effort be to characterize and improve the entire system of engineering education" (Fortenberry 2006). A transformational change in engineering education seems inevitable to prepare prospective engineers so that they can face the challenges of evolving innovation. Thus there is a need to create learning experiences more engaging, more motivating, more diversifying in a variety of settings for example in the laboratories, in the actual classroom, synchronously face to face/online or asynchronously online activities (EERC 2006). To accomplish that, we require new and better kinds of teaching and curricula, which in turn require engineering faculty to think about teaching and learning in more scholarly ways (Fink et al. 2005) and we also need to "get on with the task of making deep and solid inquiries into learning processes, using the best methods we can bring to bear to advance scientific knowledge and understanding of learning from the variety of research perspectives that are available" (Anderson et al. 2000) and need to focus "to the emergence of a new research trend that attempts to develop better understanding of the nature and processes of teacher change and the factors that affect these processes" (English 2002).

"Problem Solving" (Polya 1957; Carlson & Bloom 2005) does not mean solving well-structured problems rather it means "wrestling with ill-structured problems" (Schoenfeld

1992; Schoenfeld 1985), solving "open-ended" problems (McGinn & Boote 2003) and "modelling of complex problem situations (Lesh & Harel 2003). "Problem solving is the activity that occurs when the individual (or individuals) concerned is (or are) faced with a problem situation for which the precise nature of the problem and its solution are not initially evident" (Tall 2013, p.176). Moreover, solving problems having contradictions rather than just compromising on design parameters is crucial for innovative designs. The growing trend of design thinking (DT) (Hentschel & Czinki 2013; Noweski et al. 2012) and Theory of Inventive Problem Solving (TRIZ) in engineering education (Stratton et al. 2010) and design industry (Ilevbare et al. 2013) motivated the engineering educators and practitioners to combine the best attributes of both (Wits et al. 2010) and redesign the way we teach problem solving to prospective engineers. Design thinking is not only being used as a methodology but also as a well-defined process and mindset throughout this research (Scheer et al. 2012; Scheer & Plattner 2011). TRIZ will be integrated during the IDEATION process of to make it more structured and systematic for idea generation.

2. Research Design

The main features of this qualitative research design are explained as followings:

2.1 Research Question

Guided by Russian "Theory of Inventive Problem Solving" known as TRIZ and human-centered methodology of design thinking, our work is focused on the integration of both in an effective and complimenting way. Our research is guided by the following research questions: how to redesign the way future engineers learn to solve inventive problems?

2.2 Participants

In the quest of finding answer to the above research question, we invited six lab engineers who have joined an engineering college right after completing their bachelor's degree and their current responsibilities were to conduct lab sessions for all the related engineering courses. They helped the researchers during ideation phase in designing the activities for future engineers. We also selected nine internees using peer assessment at the end of a crash course on design thinking. All of them were either engineering or computer science students from mixed sessions/years at a private engineering college of Pakistan. These prospective engineers are looking forward to professionally grow and develop themselves as inventive problem solvers so that they can improve their design as well as problem solving skills. During the internship, the internees have taken up different design challenges and try to solve contradictory problems using design thinking methodology and 40 inventive principles of TRIZ.

A sample of demographic data is given in Table 1. Actual names were replaced by 3 lettered pseudonym for anonymous purpose with the consent of lab engineers and students.

Table 1: Sample demographic & prior experience data for research participants

Student Name	What is your major or field of interest?	What is your prior experience of design thinking?	What is your prior experience of TRIZ?
Ahmad	Electrical Engineering	I just know that there exists something called design thinking.	None
Fahad	Electrical Engineering	None	None
Ali	Computer Science	None	None

2.3 Data Collection

Data were collected in the form of written design responses against the designed problems whereas students were instructed to work in a group of twos, threes or fours. The submitted group works were scanned to convert them into electronic format. The problem solving sessions were also video recorded to capture the affective aspect during the problem solving practice over a period of 10 weeks. Internees also maintained reflective journals that helped researchers to triangulate the data during the data collection phase.

2.4 Data Analysis

The researchers adopted Miles and Huberman's (1994) operational definition of data analysis in this research, "we define [qualitative data] analysis as consisting of three concurrent flows of activity: data reduction, data display, and conclusion drawing/verification" (Miles & Huberman 1994, p.10). "The process of selecting, focusing, simplifying, abstracting, and transforming the data that appear in written-up field notes or transcriptions" (Miles & Huberman 1994, p.10) is referred to as data reduction/condensation. Data display was the second flow of analysis concerning a rational and concise information delivery. Interpreting data and answering research questions helped researchers to draw conclusions and verify them. The constantly iterative data reduction, display and conclusion drawing/verifications (Miles & Huberman 1994) made data analysis an interactive process as shown in figure 1. The researchers used triangulation at data collection level and team discussions throughout the research to address the quality of the research (Creswell & Miller 2000).

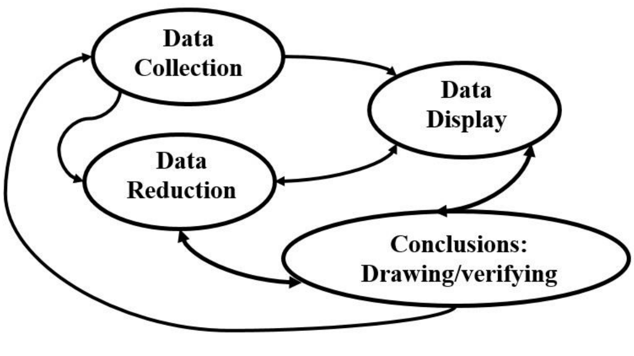

Fig. 1. Components of Data Analysis re-drawn from (Miles & Huberman 1994, p.12)

3. Results and Discussion

First phase of discovery in the design thinking process served as a solid underpinning for the next phases. By exploring the needs of prospective engineers, authors strived to create meaningful solutions of the critical issues related to their lacking skills while solving inventive problems. We moved forward with a challenge , *how to redesign the way future engineers learn to solve inventive problems* as well as with systematic interconnected phases that allowed us to review the undertaken challenge and to update our knowledge and idea repository. We started building our team of researchers, educators, and practitioners with an initial planning to move ahead to face the above challenge. The research path diverged and converged several times in between the different phases. Mid-career engineering educator, lab engineers and senior undergraduate students were selected as our respondents; and engineers, designers, educators and researchers as our audience. The researchers kept on refining the working plan from the start till the end of the first implementation of the research project. Engineering educators collaborated with international TRIZ practitioners, lab engineers and graduate students to understand the insights of the problem addressed. We observed and investigated the experiences of engineering students in design projects that guided us pick and choose the tasks fostering inventive problem solving skills and to select inductive teaching and learning methods supporting design thinking. During the second phase of interpretation, we transformed our respondents' stories into meaningful insights. Observations, field notes, informal interviews with students and educators fueled the actionable redesigning to progress. Before moving to next phase, we narrowed down our focus to some convergent points to help us move ahead in ideation phase. The structured idea generation using 40 inventive principles during the ideation phase resulted in a repository with innovative ideas and resources to promote inventive problem solving skills among future engineers as depicted in fig 2. For prototyping during the experimentation phase, we allocated 2-day workshops for the respondents and tried new ideas to get their feedbacks during those sessions. After integrating feedbacks to the following sessions helped researchers, educators, learners and practitioners to make sense of what is being intended, why we need it and how can we achieve it.

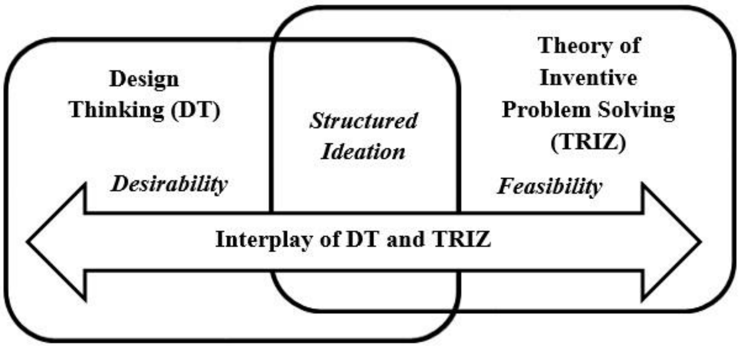

Fig. 1. Integrating Design Thinking with TRIZ

Our way of integrating inventive problem solving with design thinking resulted in a slow but continuous improvement during the evolution phase. Researchers kept tracking and recording the learning instances throughout the research using multiple tools and services. At the end, the authors outlined the next steps in planning, sharing the workable ideas with potential audience, and the guidelines for documenting the whole process. The findings showed subtle but important signs of improvement during the initial attempt of integrating design thinking and TRIZ. The experimentation and evolution phases besides all the other phases worked in a cyclic and interactive manner and continuous improvement in inventive problem solving skills of respondents made it a success story in the end. The respondents were also been able to identify the design thinking processes from their previously submitted work and in daily life's simple designs. This research will help participants to grow as more interactive, innovative and creative design thinkers and TRIZ practitioners who will be ready to make positive changes in the real world by transforming their natural powers to design thinking and inventive problem solving. It also resulted in lying down a concrete foundation for future research and practice in engineering education using the integrated process of design thinking and TRIZ.

4. Conclusions

Both Design Thinking and TRIZ have their own merits and demerits and by integrating both, the authors came up with improved results especially during the ideation phase making the experimentation and evolution phases more productive and meaningful for prospective engineers.

Acknowledgements

We acknowledge Namal College's research grant to fund this research and conference.

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RESEARCH ON CLIP IMPROVEMENT IN HEAVY HAUL RAILWAY LINE BASED ON TRIZ

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Abstract

Currently, some specific problems exist in heavy haul railway fastener system, such as concrete tie deterioration, failure of plastic plate, insufficient restrict effect on plastic plate, and so forth. These could be solved by adopting TRIZ theory and CAI software. According to the structure of II elastic clip, basic functional model is built in Goldfire Innovator. By analyzing the functions that need to be improved, using inventive principle, substance-field model, system evolution laws and other tools, further researches are conducted and corresponding solutions are proposed. Ripple damping plastic plate structure, tofu-like plastic plate, ringlike (spherical) restrict of plastic plate and other solutions could improve original system function.

Keywords: TRIZ, functional analysis, inventive principle, substance-field model, system evolution

1. Introduce

Heavy haul railway is an internationally recognized trend of rail freight development. There are very high efficiency and benefits in the heavy haul railways which are suitable for large amount transport of mass bulk goods, especially for iron mineral, coal etc. With the promotion of high and new technology, particularly the increase of truck axle load, the train transport capacities have been boosted substantially. Take Chinese Datong-Qinhuangdao heavy haul railway for example, its yearly transportation is more than 450 million tons, and it has become one of the busiest railway lines. However, heavy haul railway has a great destructive effect on the track because of the increased axle load. According to a railway industry survey conducted by the University of Illinois at Urbana-Champaign (UIUC), rail seat and concrete tie deterioration, failure of plastic plate and gauge apron plate, insufficient restrict effect on plastic plate, are identified as the primary factors limiting railway line's life[1][2][3][4].

With the further expansion of heavy haul railway market, it is significant to carry out research on rail clip and to settle the problems. Thus, a function model of elastic clip system is established by Goldfire Innovator. With the theory of inventive problem solving (TRIZ) as a guide, the functions that need to be improved or optimized are analyzed. Then, several new solutions are proposed in the design of heavy haul railway clip by using inventive principle, substance-field model, system evolution laws and other tools. Ripple damping sleeper plate structure, tofu-like plastic plate, ringlike (spherical) restrict of plastic plate and other solutions could improve original system function. It is good to advance the quality of heavy haul railway and meet the requirements.

2. System Function Analysis

From a designing point of view, any component within a system must have its purpose of existence, which provides function. It could reveal the purposes of the components' and their performances by using functional analysis system technique (FAST), and then discover the roots of the problems. Finally, the problems could be solved with creative design tools. Therefore, the function analysis must be established on a certain product. By using functional analysis, we would set up a foundational product functional model for subsequent work.

Fig1 shows the structure of elastic clip. It consists of the following components: spring fastener that withholds rail, rail spike (including nut and screw) that regulates clamping force of fastener, gauge apron plate that maintains and adjusts gauge, nylon baffle block that supports gauge apron plate, plastic plate that provides elasticity and insulativity, etc[5].

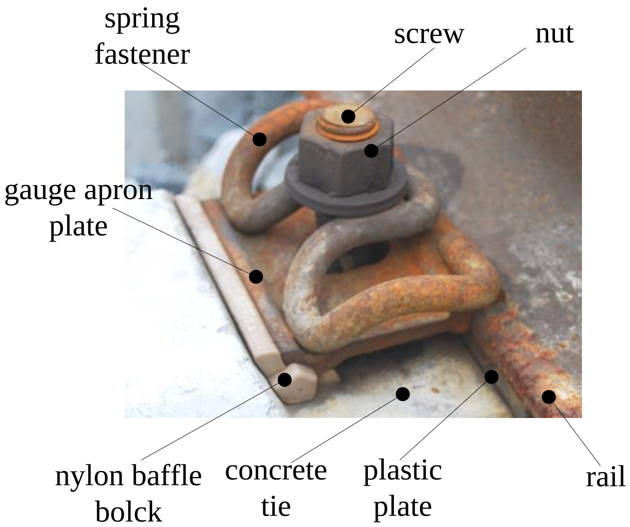

Fig.1. the structure of II elastic clip

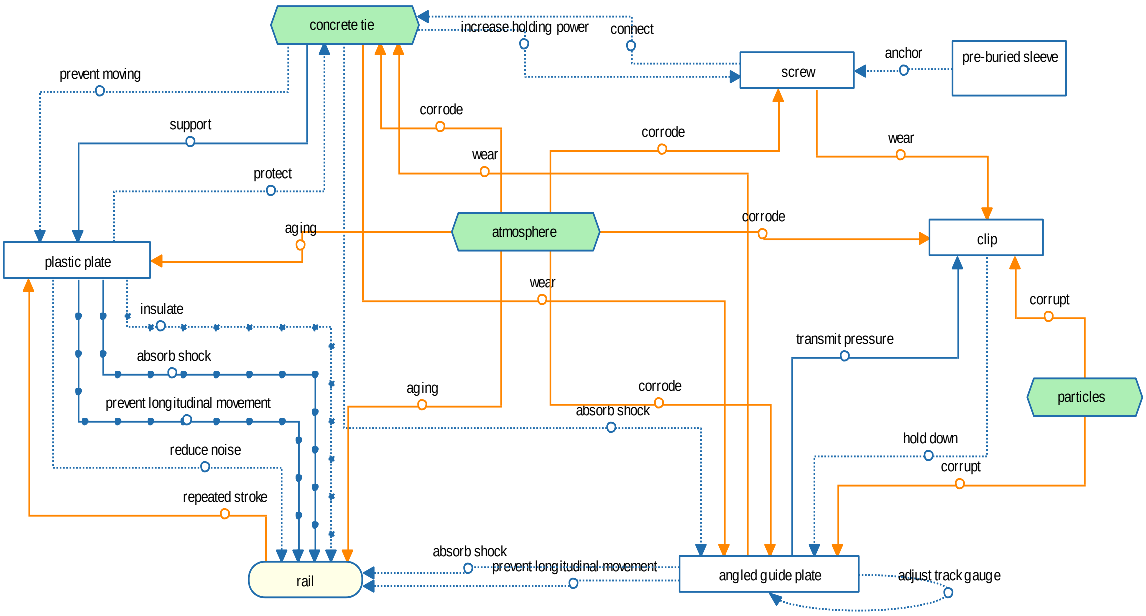

Fig.2. Function model based on II elastic clip

The internal components of clip system include: plastic plate, height adjusting plate, concrete tie, gauge apron plate, spring fastener, screw, nut, and nylon baffle block. The external components include: rail, soil, air, foreign particles (such as iron embroidery, dust, etc). In Goldfire Innovator platform[6], the relationships between the various components of the clip system are shown in Fig 2, where the green polygon frame, white rectangular box with yellow rounded rectangle box, corresponds super system, component and target. Yellow arrow and blue arrow represents harmful effect and useful effect respectively. The solid line stands for sufficient effect, while the dashed lined stood for insufficient effect.

According to the function model[7], 6 problems are concluded: 1) concrete tie deterioration, 2) bolt loosing, 3) spring fastener broken, 4) ageing of plastic plate, 5) failure of plastic plate, and 6) insufficient restrict effect on plastic plate.

3. Application of Creative Tool & Generation of Solution

3.1. Concrete Tie Deterioration

Due to the dynamic load of train and adverse environmental condition, concrete tie would bring about some damaging problems, such as crack, break, crush, gouges, etc. Especially under heavy load conditions, the damage would be more serious.

From the function model, it is obvious that plastic plate could not absorb the load and shock that are transferred to the concrete tie. To improve the strength and elasticity of plastic plate and enhance the ability to support the heavy load, the thickness of the plastic plate should be increased, which will bring about disadvantageous influence to the structure. Actually, increasing the thickness of the plastic plate leads to the rise of the volume. Thus, this conflicting situation falls into two general technical parameters[8]:

Failure to improve: strength (14),

Undesired result: volume of stationary objects (8).

Then Contradiction Matrix is used to find the appropriate principles. TRIZ recommended that principle 9, 14, 15 and 17 could be applied to solve the problem. Starting with recommended principle 14, it depicts that parts of the object could use linear or spherical surface instead of curve or plane, parallelepiped or cubic could be translated into spherical structure. According to the principle, the surface of plastic plate could become unsmooth, that is cambering transformation in TRIZ. Thus, ripple damping plastic plate structure is proposed, shown in Fig 3. The outside surface looked like a disc. It consisted of two parts: rigid skeleton and built-in elastic padding object. The rigid skeleton viewed from the side is corrugated, and the whole structure is a radial center-folded shape. A plurality of cavities is formed between the folds. The cavity is filled with elastic fillers.

With the external heavy load, ripple damping plastic plate structure has a triple vibration damping process: the compression shear deformation of the elastic fillers could absorb energy and reduce vibration, the friction between the rigid skeleton and the elastic fillers could dissipate energy, and the skeleton deformation in a plane could also reduce vibration. Thus, ripple damping plastic plate has a better effect of vibration damping, as well as a better impact resistance. It could replace the existing plastic plate under rail.

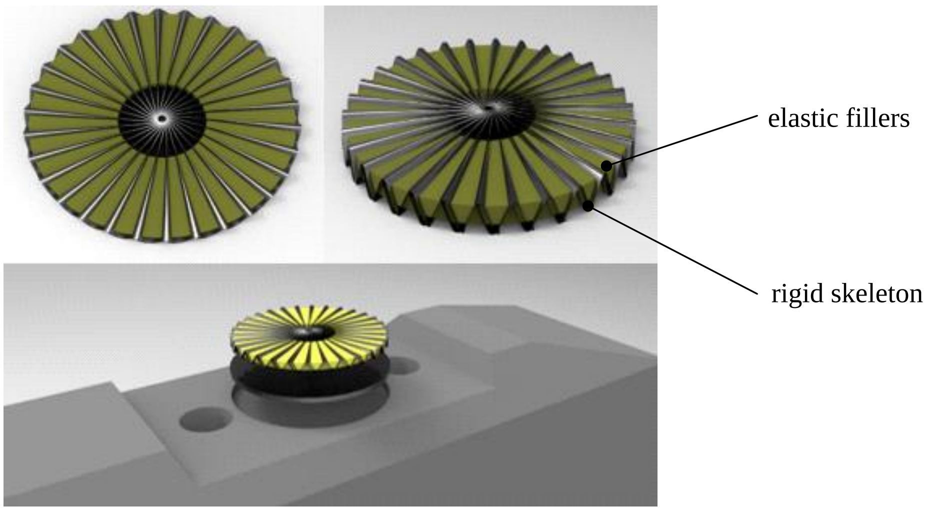

Fig.3. ripple damping plastic plate structure

3.2. Failure of Plastic Plate

Plastic plate, between concrete tie and rail, played a significant role of reducing vibration, regulating position and protecting concrete tie. In the meanwhile, it is vulnerable to damage and ageing, due to prolonged exposure to repeated high-intensity combats, as well as its own characteristics. Particularly, under heavy loads, repeated high-intensity combats would be more intense, which would accelerate the ageing process, result in the failure of plastic plate.

According to the problem, it is not clear to identify the both sides of contradiction, but it could represent and analyze the problem by using the substance-field model. On the basis of the above representations, the substance-field model is established, shown in Fig 4. From the function model, the effect on protecting concrete tie from plastic plate is insufficient.

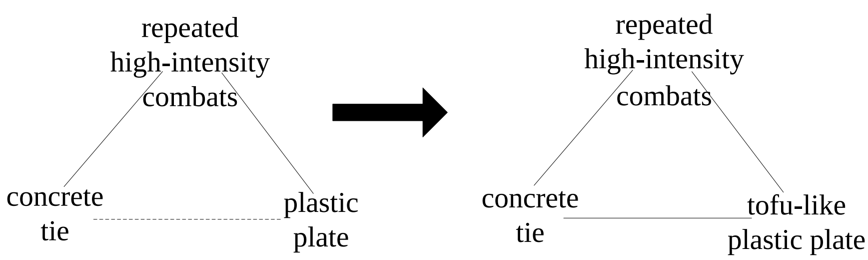

Fig.4. Standard Solutions 2.2.2

It is a non-effective model, which need to be strengthened[9]. Among the Standard Solutions, S2.2.2 could be applied to the problem. The effect of the model could be enhanced by increasing the degree of splitting plastic plate (S2), shown in Fig 4. Thus, the whole plastic plate is divided into several tofu-like patches, and is fixed into recesses of concrete tie, shown in Fig 5. The depth and distance of the recess are set based on the specific project condition. Meanwhile, the distance should not be too small in avoiding breakage of the concrete tie. The profile of the tofu-like plastic plate shows a T-shape. The exposed surface of the concrete tie connects the adjacent plastic plate. This design style could protect the concrete tie, and also it is convenient to replace the damaged plastic plate.

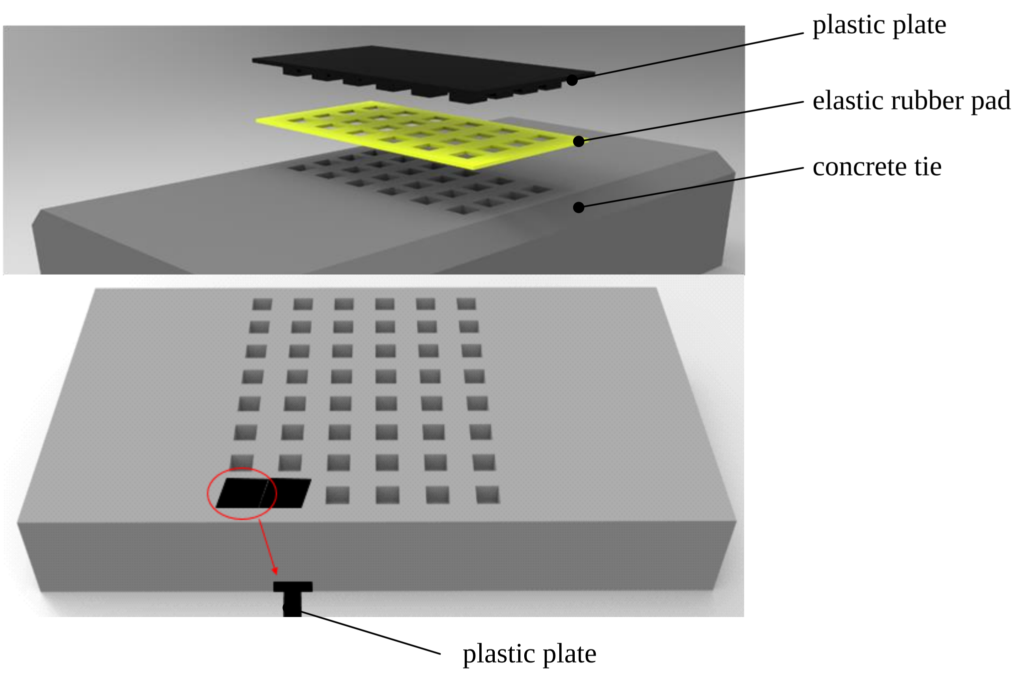

Fig.5. tofu-like plastic plate

3.3. Insufficient restrict effect on plastic plate

The restrict effect on plastic plate from concrete tie makes use of the friction generated by the contact surface. However, with the external heavy load, plastic plate would shift so that it would weaken the restrict effect from the concrete tie. For the structure, it could be solved by using Contradiction Matrix or Su-fields as shown above. Whereas, this paper shows how to use system evolution laws to solve the problem.

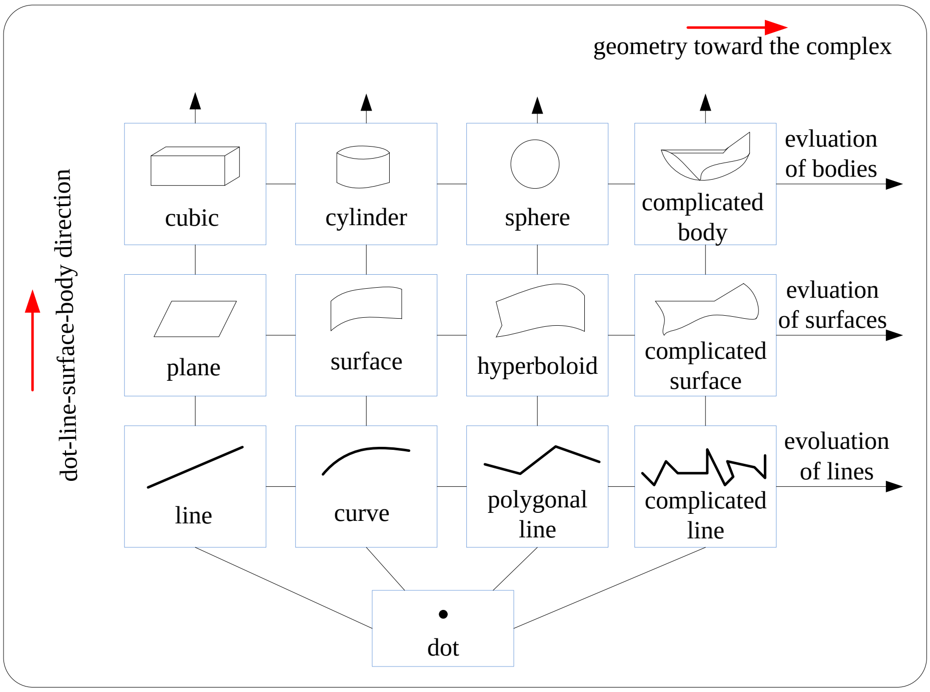

Fig.6. The coordination of geometric structures

The evolution laws indicate that the technical system would evolve towards coordination of every subsystem, coordination between system and super-system. The coordination of subsystem's parameters include intercoordination among material properties, geometric structures, sizes and masses and so forth [10].[11]. The coordination of geometric structure is shown in Fig 6.

For the problem, the geometrical shape of the plastic plate could be changed according to the evolution law, especially the evolution of bodies. Thus, two spacing rods with rigid sphere on the end, is settled in the plastic plate vertically, which could prevent the plastic plate from springing, shown in Fig 7. In the meanwhile, this structure could retain the function of absorbing vibration and protecting the concrete tie. Additionally, the edges of the plastic plate ought to extend appropriately, avoiding the damages of concrete tie caused by the stress concentration due to the direct contact between rigid sphere and concrete tie.

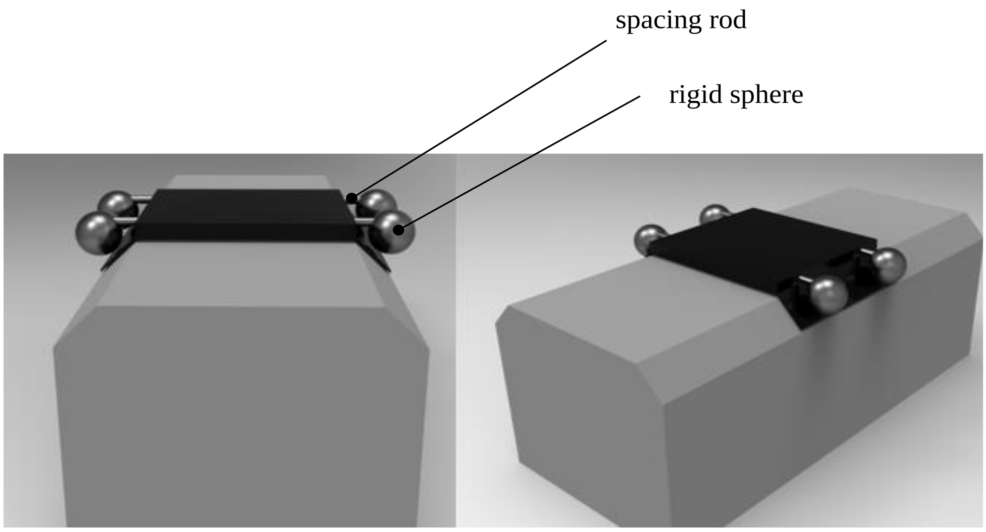

Fig.7. ringlike (spherical) restrict of plastic plate

4. Conclusions

This project improves the function of heavy haul railway fasteners. With the platform of innovation CAI and the tools of TRIZ, several solutions are proposed which could be implemented with engineering and patentability. On the basis of the structure of II elastic clip, a function model of elastic clip system is established by Goldfire Innovator. According to the functional model, 6 problems are concluded. Then, using inventive principle, ripple damping plastic plate structure is put forward to decrease concrete tie deterioration. Using substance-field model, by changing the shape of the plastic plate, a tofu-like plastic plate is come up with, which is divided into several tofu-like patches, and is fixed into recesses of concrete tie. Based on the evolution laws, by evolving the geometric structure of the plastic plate, a ringlike (spherical) restrict of plastic plate is given to overcome the Insufficient restrict effect on plastic plate. Among the solutions, a patent is applied for ripple damping plastic plate (application No: CN 104088945 A).

Acknowledgements

We are very grateful to Chengdu Brach of Global Engineering Technology Group for their advice and creative solutions. We also thank Li Yan and Li Wenqiang for their instructions and illustrations.

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RESEARCH ON TRIZ INTEGRATED AFFORDANCE ANALYSIS

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Abstract

Aimed at the analysis issue on the relationship between technical system and the environment in the evolution process of technical system, the integration of TRIZ with affordance analysis provides technical support for function solving and improvement of technical system. The method combines the analogical reasoning method and regards function solving, diagnosis of the solution and improvement of the solution as the main line. Through situated analogy, affordance is put forward to describe the relationship between technical system and the environment. The affordance of analogy source design is to be realized to find out the poor affordance of the target design, thus turning to TRIZ theory for analysis and solution. The paper takes the evolution process of spiral drum for shearers as an example, verifying the practicality of this method in the evolution process of technical system.

Keywords: TRIZ; technical system; evolution; analogy; affordance

1 Introduction

The evolution of technical system is essentially an innovation process. Using TRIZ theory for analysis and solution can be divided into two types: function solving and improve design of technical system. Both of them require environment support and introducing the driving knowledge that describes the relationship between technical system and the environment to support the design of technical system evolution. Applying TRIZ integrated other design theories and technical methods, which can properly describe the interactive relationship between technical system and the environment, provides technical support for the solution transformation of TRIZ. Therefore, it has become an important research on TRIZ method application.

Based on similar theory, Tan Runhua and Ma Lihui [1] applied the similarity analysis between source design and target design in evolution principles and resources to provide support for TRIZ solution. FBS model [2], the hotspot in current research, realizes solution through a step-by-step and detailed description of function, behavior and structure. However, the model cannot show to describe the relationship between technical system and the environment. Brown [3] put forward the M (D, E) model to describe the interactive relationship between technical system and the environment. Based on the analysis of the transitive relationship of affordance, Maier and Fadel [4] provides GAST (Generic

Affordance Structure Template) and ASM (Affordance Structure Matrix) to describe the relationship between the system and the environment.

Combining the analogical reasoning method, the paper integrates the affordance analysis method with TRIZ, in which adopts affordance to indicate the relationship between technical system and the environment. Through situated analogy of using affordance to driving innovation, the affordance of analogy source design is realized to indicate the poor affordance of the target design, and then TRIZ theory is used for analysis and solution. The method is verified practical by taking the example of the evolution process of the cutting drum of shearers from driving drum to spiral drum.

2 Affordance Based on Analogy Reasoning

2.1 Affordance Representation and Problem Definition Mode

If there are two components A and B, it is said that the component A has affordance to B when B is generated the output stream f2 by the input stream which is the output stream f1 from A. B_A symbolizes the affordance from A to B as figure 1 shown. As an example, two gears transmission can be described by affordance as the driving gear inputs the force and velocity to the driven gear so as to drive the rotation of driven gear.

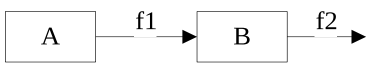


Fig. 1. The Model of Affordance

Affordance (A) representation is defined as the process based on affordance that conveys the cognitive contents of the relationship between technical system and environment in situated analogy, by which the analogy of affordance between source of analogy and target design can be supported in representation. In the process of the TRIZ function analysis, the interaction relationship of the function element can be taken into the sections as harm, utilize, excessiveness and insufficiency. The function relationship between A and B can be described and explained by affordance. The description is that the element B completes the expected behavior when A inputs and influences B. Moreover, the affordance is also the polarity which has positive and negative affordances because there are good and harmful affordance relationships. Thus, the affordance pattern needs to be more accurate expression. In summary, the affordance relationship is expanded and symbolized in this paper as shown in Table1.

Table 1

The Affordance Relationship

Affordance Relationship	Symbol	Explanation	Relevant Function Relationship
Useful Affordance	B_A^+	A has the useful affordance to B, which means that the existence of A can ensure the expectation behavior of B.	Useful Relationship
Harmful Affordance	B_A^-	A has the harmful affordance to B, which means that the existence of A can waste B or cause the negative affordance of B.	Harmful Relationship

Excessive Affordance	B_A^{++}	The existence of A causes the output of B to exceed the expected purpose.	Excessive Relationship
Insufficient Affordance	B_A^{--}	The existence of A causes the output of B can't achieve the expected purpose.	Insufficient Relationship

2.2 Driving Design Process of UXD Based on the A Representation

Wiggins [5] defines unexpected discoveries (UXD) as the emergent features that haven't been predicted previously by designers but emerge during the situated design. The key to realize the situated analogy is to extract UXD during building memories. UXD process supported by Affordance representations is used to find the analogy relationship which is unexpected at the beginning of design in the analogy design process. The analogical information delivered from source design to target design can be divided into main information and additional information. Main information is the information which is hopefully delivered to the analogical object from analogical source and is relevant to the design object; additional information is the information which is unexpected delivering to the target design with the main information for the effect of similarity principle. For the target design, it is the additional information generated during the analogy process is easier to be searched from the source design.

In Affordance representation method, the type of A representations are divided into the AUA (Artifact-User Affordance) and AAA (Artifact-Artifact Affordance), which describe the Affordance relationship between physical device and operator and the Affordance relationship between physical device and physical device respectively. They are also divided into positive and negative aspects in polarity. UXD will be generated by the harmful AAA or AUA in the process of situated design (see Fig.2, in which the rectangles represent the design data and the hexagons represent the processing method).

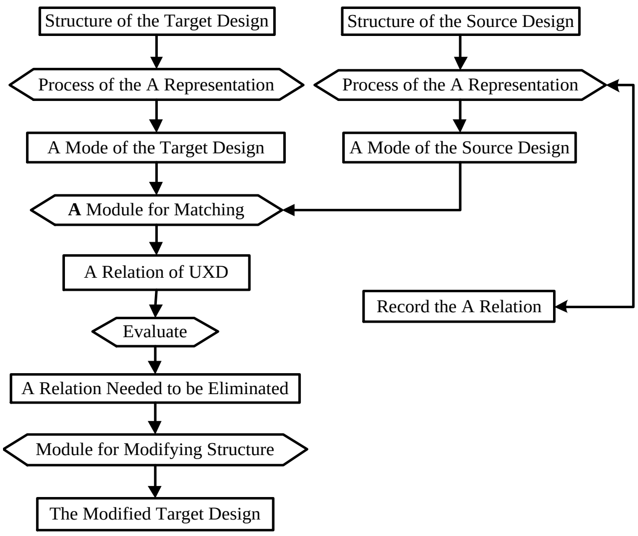


Fig. 2. The Process of Situated Analogy Based on A Representation

It is shown in figure 2 that source design and target design are role reversal. The affordance relationship can be discovered by the delivered into target design via the affordance analysis of the source design. Affordance representation module defines the affordance relationship by the affordance analysis. A matching module means that the Affordance representation of target design matches with the Affordance representation of source design, thus the unexpected affordance relationship in the target design which can be ascertained. Then they are delivered into the evaluation module. The evaluation module can find the more benefit or the block section for technology system evolution in the unexpected affordance relationship. To emphatically analyze these affordance relationships has a great impact on the system evolution efficiency.

The situated cognitive process is applied Affordance representations to find the negative affordance in the analogy source design. This process is helpful to find the negative affordance in the target design and solve the function problems and the improvement problems of technology system in the TRIZ analysis. TRIZ can be the effective tool to solve the affordance. The results driven by UXD based on the affordance representations can be transformed into the substance-field model or contradiction problems of TRIZ.

3 Design Process Integrated Affordance Representation with TRIZ

Based on the above technical theory, this paper studies the design process integrated Affordance representation with TRIZ. The main steps (see Fig.3) are introduced as follows.

Step1: Requirement Analysis Module. This process analyzes and summarizes the information data obtained from the market research and the technical department prediction. It is described by the natural language form.

Step2: Function Analysis Module. Function decomposition is a process that the function requirement is converted to function structure constituted by function unit. Function definition is a process that function can be converted to the definition of functional semantics by the support of the function base.

Step3: Matching Module of Effect Example. It can find effect examples associated with the design problems by searching the effect base and the effect example base.

Step4: Situated Analogy Module Driven by UXD. Based on Affordance representation, the affordance relationships among each subsystem in the technical system are obtained through the affordance analysis. Through analyzing the situated design, the UXDs are extracted and the negative affordances are found out.

Step5: Analysis and Solution Module of TRIZ. TRIZ standard problem definition is to transform the negative affordance from diagnosis into the standardized description of TRIZ in that it can be easy to solve by the TRIZ theory. Analysis and solution of TRIZ is a process that can solve the design problems generated from function analysis and affordance analysis and through standardized treatment， in which the solving tools and knowledge of TRIZ for function, contradiction and substance-field problem are used. ARIZ algorithm will be enabled when satisfactory solution failed to be found in the analysis and solution mode for the problems of substance-field and contradiction etc.

Step6: Post-Processing Module. Through the analysis and solution module of TRIZ in step5, the function unit solution sets have been obtained. To combine them together and verify them, a design scheme will be obtained.

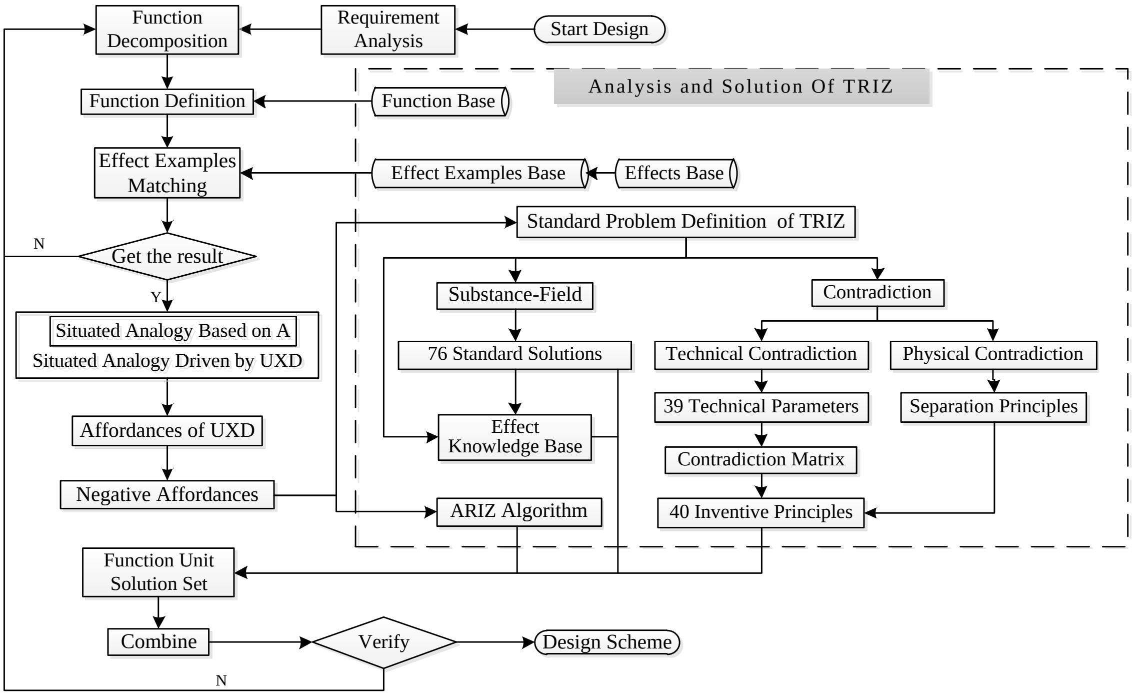


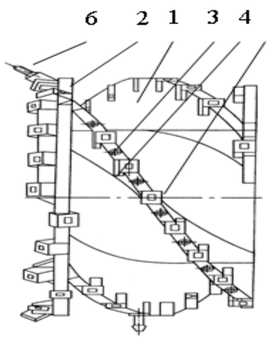
Fig. 3. The Design Process Integrated A Representation with TRIZ

4 Example Analysis

The paper takes the conceptual design of electrical haulage shearer's cutting drum [6], as an example to demonstrate that the method is feasible, in which the cutting drum evolved from the driving drum to the spiral drum is driven by the integrated process.

4.1 Working Principle of Electrical Haulage Shearer

The electrical haulage shearer is applied to coal mining, whose main function is to cut coal from the coal seam by mechanical means and transport the lump coal from the coal mine to the outside. Compared with the original driving drum, the structure of the evolved spiral drum is shown in figure 4, which has the functions of cutting coal and loading coal. When working, the cutting pick 6 cuts the coal from the coal seam and then the axial thrust of helical blade 1 pushes the coal into the scraper conveyor.



1-helical blade 2-end plate 3-toothholder 4-nozzle 5- cylinder hub 6-cutting pick

Fig. 4. The Structure of Evolved Spiral Drum

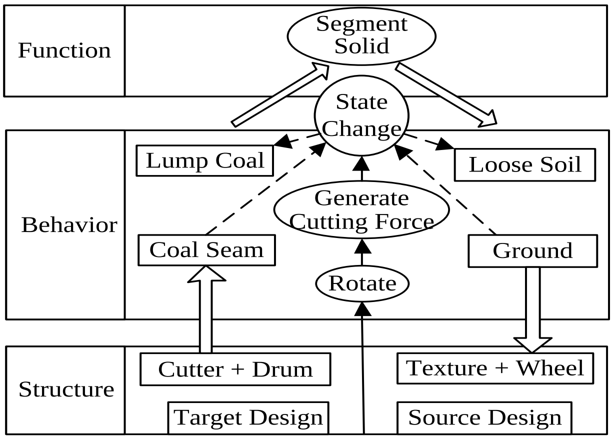


Fig. 5. The Structure Generating Process of Shearer Drum Based on Situated Analogy

4.2 Structure Solution Obtained by Analogy

The analogy of function and structure is shown in Figure 5, in which the example that wheel rubs ground is taken as the source of analogy and the cutting drum is taken as the target design. The source design and the target design have the same function, which is dividing solid into loose material. UXD is found from the analogy sources by analogy and then mapped to the target design so as to generate the behavior of realizing function. At the same time, the structure of realizing behavior in analogy source is also regarded as the UXD of target design and to be delivered to the target design to obtain structure. The result of analogy is shown in Figure 6.

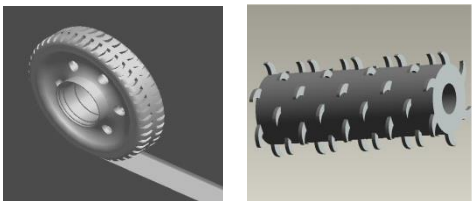


Fig. 6. The Analogy of Wheel and Shearer Drum

4.3 Solving Process of UXD Based on Affordance Representation

The process includes two aspects: 1) to execute Affordance representation and find UXD in the target design; 2) to execute Affordance representation and find UXD in the source design. The Affordance representation and UXD analysis for source design plays an important auxiliary role for the improvement of target design.

4.3.1 Affordance Representation and UXD of the Target Design

The distribution model of function and environment proposed by Brown, that is M (D, E), is introduced to the study, in which device (D) indicates the equipment existing in the physical world , environment (E) indicates elements except for equipment in the physical world. To separate the elements of D and E can highlight the design purpose, which would be emphasized in the cognitive process of UXD. The M (D, E) model of the concept solution of shearer cutting drum obtained in section4.2 is built. D= {drum, cutting pick}, E= {coal seam, cut coal, air, gas, operator}. Affordance relationship of each element is represented in Table 3. Owing to the limited space, only Affordance representations related to the design problem is listed in this paper.

Table 2

The Affordance of Shearer Drum

Serial Number	element(A,B,C)	Property	Symbol	Remark
1	Roller (A) Cutting Pick (B)	+AAA	B_A^+	A and B are fixedly connected, which can ensure that B completes cutting.
2	Roller (A) Cut Coal(B)	-AAA	A_B^-	Cut coal can wear roller.
3	Cutting Pick (A) Coal Seam(B)	-AAA	A_B^-	The existence of B can wear A.
4	Coal Seam (A) Air (B)	-AAA [UXD]	B_A^-	The gas released by coal seam can polluted air.
5	Cutting Pick (A) Coal Seam (B) Air (C)	-AAA -AUA [UXD]	$C_B^- \cap A_B^-$	Cutting pick can generate high temperature by the friction of Coal Seam, and mixing gas with air can generate explosive gases.

In table 2, the affordance 1 is expected by the design purpose. The affordances 2 and 3 generated during the design process are unexpected, negative and inevitable. However, their effects can be reduced through adjusting the parameters such as material, system structure so that UXD is not marked here. The affordances 4 and 5 are unexpected and haven't been generated during the function decomposition. However, they are significant hidden troubles to system. The existence of these affordances provides new targets for the design so that [UXD] is marked in the table. The affordance 5 does harm to the elements of equipment and operator in the environment so that it is marked with -AUA related to people and the -AAA related to substance.

Then, the analysis results are transformed to the form of TRIZ. The substance-field models of affordances 4 and 5 are shown respectively in Fig.7 and Fig.8. According to the substance-field model, solution method can be retrieved from the knowledge base of TRIZ. Fig.8 describes the harmful effect model, of which the harmful field can be cancelled out by introducing the new field. As a result, the equipment for cutting and cooling is required here. For the substance-field in Fig.7, the equipment for reducing harmful elements in the air is required to been introduced. However, other elements in the air should be taken into account for the specific design of this equipment so that the further affordance analysis is necessary.

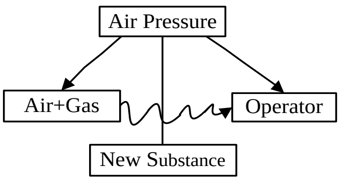


Fig.7 Su-field of Breathing Harm

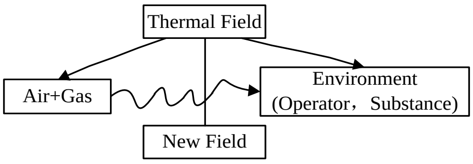


Fig.8 Su-field of Gas Danger

4.3.2 *Affordance Representation and UXD of the Source Design*

The affordance of source design is described by two correlations between source design and target design, that is：1) The scene of source design is complete and clear so that the UXD of source design can be found easily by affordance analysis; 2) Some of the implied characteristics of target design are similar to the source design so that they can be extracted by analyzing the source design.

The affordance analysis of source design is similar to design target. The M (D, E) model is built. D= {wheel, texture}, E= {ground, loose soil, dust, air, operator}. The Affordance representations for each element are shown in table 4.

In table 3, the affordances 1 and 4 are target information transmitted from source design to target design in the analogy process. The affordances 2, 3 and 5 are additional information in the analogy process, which is implicit and can't be found easily in the target design. These scenes are generated by combining with the scenes of source design in the affordance analysis, of which characteristics aren't noted during the design process. Thus, they are marked with UXD. While UXD obtained, the process can be switched to the analysis of TRIZ. The UXD of affordance 2 is a phenomenon generated by wedge effect. The wedge effect can provide solution method for loading coal, which is a new function requirement generated by function decomposition. According to wedge effect, spiral transmission is taken into account, which can transform the circumferential movement into the axial movement and implement the work of loading coal. Therefore, the cutting drum can be assembled with the spiral push plate. In order to meet the work of cutting pick, the pick should be migrated to the spiral push plate. As a result, the cutting drum is evolved from the driving drum to the spiral drum (see Fig.9).

Table 3

The Affordance of Wheel

Serial Number	element(A,B ,C)	Property	Symbol	Remark
1	Wheel(A) Texture(B)	+AAA	B_A^+	A and B are fixedly connected, which can ensure that B completes cutting.
2	Wheel (A) Loose Soil(B)	[UXD]	B_A	While the wheel rolls on the ground, the ground substance would spatter towards two sides of wheel.
3	Wheel(A) Air(B)	[UXD]	B_A	The air swirl is caused by the rotation of spiral drum
4	Texture (A) Ground(B)	+AAA -AAA	B_A^+ ; A_B^-	Ground rubs the texture in that the texture is worn.
5	Texture (A) Air (B) Dust (C)	-AAA -AUA [UXD]	$B_A^- \cap C_B^-$	The air swirl is caused by the texture and the air swirl cause dust blowing.

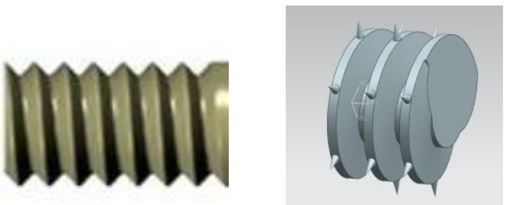


Fig.9 Screw and Shearer Screw Drum

In addition, the affordance 5 that dust pollutes environment is undiscovered UXD in the target design, which also exists in the target design. The process can be switched to the analysis module of TRIZ and the substance-field model is shown in Fig.10. In this substance-field model, the field (pressure) originates from the air swirl which is a UXD of source design caused by the rotation of spiral drum. The harmful field can be cancelled out by introducing the new field. Combining with the substance-field model shown in Fig.8, the spray device can be used to solve problems found in Fig.8 and Fig.10. As a result, the evolution happened in the spiral drum is evolved in that the useful function is added to the system. The concept solution of spiral drum with spray nozzles is shown in Fig.11.

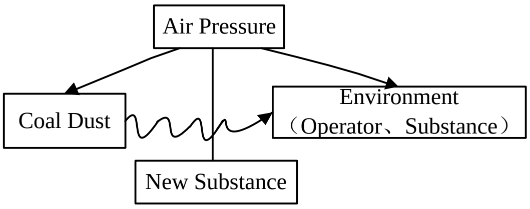


Figure 10. Su-field of Harm Caused by Coal Dust

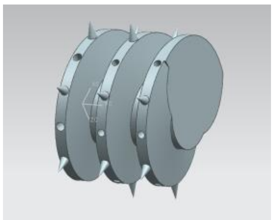


Figure 11. Spiral Drum with Spray Nozzles

5 Conclusions

The evolution process of shearers verifies the practicality of this method, in which the conceptual design of cutting drum is evolved from the example that wheel rubs ground to the driving drum and then to the spiral drum and finally to the spiral drum with spray nozzles. Combining the analogical reasoning method, TRIZ integrated affordance analysis can solve the complicated problems of technical system evolution, in which function solving, diagnosis of the solution and improvement of the solution are regarded as the main line. Through situated analogy, affordance analysis is used to describe the relationship between technical system and the environment. The poor affordance of target design can be found out by realizing the affordance of analogy source. In a word, the method can provide the basis for analysis and solution of TRIZ.

Acknowledgements

This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation.

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TRIZ*fest* 2015

SIMPLIFICATION OF SYSTEM OF STANDARD SOLUTIONS FOR TRIZ BEGINNERS USING MAR OPERATOR

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Abstract

The System of Standard Solutions is one of the powerful TRIZ tools for solving common inventive problems, but due to its complexity, it is difficult to understand and apply, especially for TRIZ beginners. This paper aims to simplify the System of Standard Solutions by investigating into the contents of suggestions in each standard solutions and compiling them into a user-friendly operator called MAR Operator. The MAR Operator consists of 3 suggestions for Modifying, Adding, and Replacing the component (substance and/or field) of the system with the purpose to generate ideas for improving the useful function and/or eliminating the harmful effect of the system. Case studies on wireless power transfer system for electric vehicle (EV) have been demonstrated to show its effectiveness in idea generation for solution concepts.

Keywords: TRIZ, Standard Solutions, Substance-Field Model, MAR Operator, Electric Vehicle

1. Introduction

The System of Standard Solutions is one of the advanced TRIZ tools. It was developed by G. Altshuller between 1975 to 1985 to solve common inventive problems [1]. It is used in conjunction with Substance-Field Modeling and Analysis to identify the initial problem situation and suggest suitable standard solutions [2,3]. The System of Standard Solutions consists of 76 Standards which are classified into 5 classes and 18 subclasses of which class 1 deals with improving interactions and eliminating harmful effects; class 2 deals with enhancing the efficiency of the system; class 3 deals with the evolution of the system; class 4 deals with detection and measurement; and class 5 deals with strategies in the application of the Standards [4,5]. Substance-Field Modeling and Analysis reveals the problem types of which the corresponding class or subclass of standard solutions are deployed accordingly. The problem types are mainly divided into incomplete substance-field model; insufficient or inefficient useful function; harmful effects or interaction of the systems and finally detection and measurement problem [6,7]. The minimal number of components for a complete substance-field model of a technical system comprises two substances and one field, which form a triangle through their interaction. Once a substance-field model has been formulated, a suitable solution can be searched for from the 76 Standards depending on the types of problems as in the simplified flow-chart in Fig. 1.

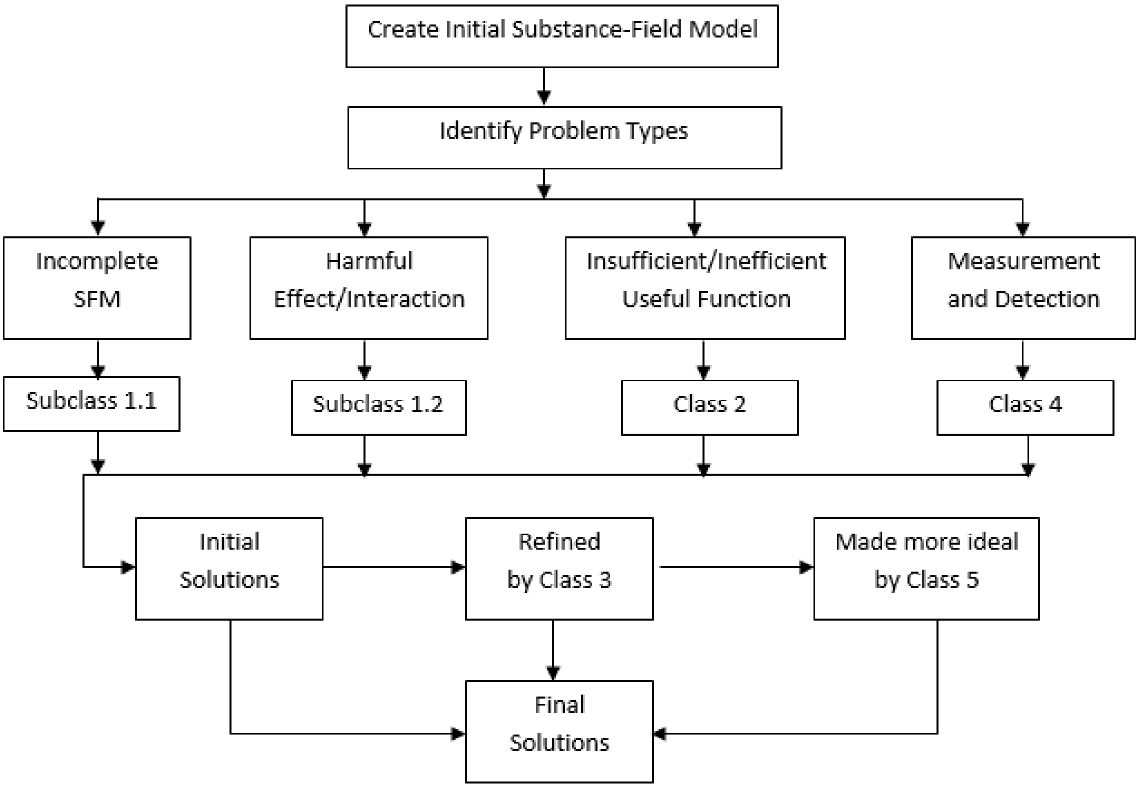

Fig. 1. Flow-chart of applying 76 Standard Solutions (Based on the flow chart of N. Khomenko [7])

2. Problems of the System of Standard Solutions

Although the System of Standard Solutions is a powerful problem solving tool developed through the research of thousands of inventive patents to define standard problems and their solutions, it is rather complicated and not easy to understand and apply, especially for TRIZ beginners. This makes it difficult for new comer to appreciate the value of TRIZ. Since 1985, many TRIZ practitioners have attempted to improve the System of Standard Solutions, pointing out the complexities and difficulties in applying the standards properly. For instance, V. Souchkov suggested remodeling of Substance-Field Systems based on Systems Theory for computer-aided design in his book "Knowledge-Based Support For Innovative Design" [8]. Semyon D.Savransky proposed Table of Standards Unification with the form of "IF..THEN.." in his book "Engineering of Creativity" [9]. Iouri Belski systematized the logic and models of Substance-Field Analysis with 5 model solutions and 8 fields of MATCEMIB in his book "Improve your Thinking: Substance-Field Analysis"[10]. Vladimir Petrov enhanced the law of increasing degree of Su-Field of Altshuller by elaborating on the general sequence of Su-Fields development and introducing additional trends [11]. There are many other attempts to improve the Substance-Field models and the System of Standard Solutions [12-16] and the most recent one is system of 111 Standards proposed by Davide Russo and Stefano Duci which organize the information of Altshuller's Standard Solutions according to functional approach [17]. These new versions of standards contribute some improvement to the development of systems of standard solutions and substance-field modeling and analysis. However, they are still complicated and not easy to understand and apply, especially for TRIZ beginners. It creates a severe obstacle on the way to attracting more people to TRIZ. Difficulty of the use of the System of Standard Solutions repels beginners from the use of this otherwise powerful problem-solving tool and TRIZ in general.

As most of the problem situations in the initial substance-field model are concerned with incomplete substance-field model, insufficient or inefficient useful function and harmful effects or interaction of the systems which are mainly solved by the standard solutions in class 1 and class 2, this paper aims to look into the suggestions in each standard solutions in class 1 and class 2 and compile them into an user-friendly way that help problem solvers generate ideas for the corresponding substance-field model without the need to look into the details of each standard solutions.

3. The MAR Operator

Since the System of Standard Solutions is concerned with manipulating components in the system and its environment for the purpose of transforming the initial Substance-Field Model into a problem-free model, the author attempts to look into the contents of each standard solutions in class 1 and class 2 which consist of totally 36 solutions, to analyze the frequently used suggestions and the components that are manipulated. The result is shown in Table 1.

Table 1

Suggestions and Components of System of Standard Solutions

Solution	Standard Solution	Suggestion			Component	
Number	Title	Modify	Add	Replace	Substance	Field
1.1.1	Building of Substance-Field Model		X		X	X
1.1.2	Improving interactions by introducing additives into the objects		X		X	
1.1.3	Improving interactions by introducing additives into a system		X		X	
1.1.4	Use of environment to improve interactions		X		X	X
1.1.5	Modification of environment to improve interactions	X	X		X	X
1.1.6	Providing minimum effect of action		X		X	X
1.1.7	Providing maximum of effect of action		X		X	
1.1.8(a)	Providing selective effect by maximum field and protective substance		X		X	
1.1.8(b)	Providing selective effect by minimal field and active substance		X		X	
1.2.1	Elimination of harmful interaction by a foreign substance		X		X	
1.2.2	Elimination of harmful interaction by modification of an existing substance	X			X	
1.2.3	Elimination of a harmful effect of a field		X		X	
1.2.4	Elimination of a harmful effect by a new field		X			X
1.2.5	Elimination of a harmful effect caused by magnetic field		X			X
2.1.1	Synthesis of a Chain Substance-Field System		X		X	X
2.1.2	Synthesis of a Dual Substance-Field System		X			X
2.2.1	Replacing poorly controlled field with a well controlled one			X		X

2.2.2	Increasing a degree of fragmentation of substance components	X			X	
2.2.3	Transition to capillary porous objects			X	X	
2.2.4	Increasing a degree of system dynamics	X	X	X	X	X
2.2.5	Changing structure of a field			X		X
2.2.6	Changing structure of a substance object			X	X	
2.3.1	Matching/unmatching frequency with natural frequency of the product or tool	X				X
2.3.2	Matching/unmatching frequency of applied fields	X				X
2.3.3	Performing two incompatible actions	-	-	-	-	-
2.4.1	Synthesis of a Substance-Field System with ferromagnetic substance			X	X	X
2.4.2	Enhancing efficiency in Ferromagnetic Substance-Field System using ferromagnetic particles		X	X	X	X
2.4.3	Enhancing efficiency in Ferromagnetic Substance-Field System using magnetic liquids		X		X	
2.4.4	Enhancing efficiency in Ferromagnetic Substance-Field System using capillary or porous structures	X			X	
2.4.5	Introducing additives to Ferromagnetic Substance-Field Systems		X		X	
2.4.6	Introducing ferromagnetic particles to the environment		X		X	
2.4.7	Increasing controllability by physical effects		X		X	X
2.4.8	Increasing a degree of system dynamics	X	X	X	X	X
2.4.9	Changing structure of a field	X				X
2.4.10	Matching Rhythms in Ferro-Field Models	X				X
2.4.11	Interaction between either an external electromagnetic field and electrical current, or between two currents			X		X
2.4.12	Electro-rheological liquid with viscosity controlled by an electric field			X	X	

As shown in Table 1, the suggestions of each standard solution in class 1 and class 2 can be categorized into 3 types namely, Modify, Add and Replace which act on the components (substance and/or field) of the initial Substance-Field Model and/or its environment. The author has summarized it into a table called the MAR Operator as shown in Table 2.

Table 2

The MAR Operator

Number	Operator Name	Description
1	M: Modify	Modify the existing substance and/or field in the initial Substance-Field Model and/or its environment.
2	A: Add	Add new substance and/or field into the initial Substance-Field Model.
3	R: Replace	Replace the existing substance and/or field in the initial Substance-Field Model with new substance and/or field.

Instead of using the formal System of Standard Solution, problem solvers can easily use the MAR Operator to generate ideas for the initial substance-field model to find the solution concepts. Usually the solution concepts obtained are practical enough, but if more ideal solutions are required, they can be further refined by using the standard solutions in class 3 and 5 as in the simplified flow-chart in Fig.1.
It is noticeable that the Standard Solution 2.3.3 is an exception; it has no relation with MAR Operator. The Standard Solution 2.3.3 is a direct application of Inventive Principle 19c (Periodic Action, use of pauses) to Substance-Field Model. Since MAR Operator reflects only "direct" operations with Substance-Field Model, it cannot reflect such "tricks". Hence, this Standard Solution should be considered separately.

4. Case Studies and Discussion

In order to test the effectiveness of the MAR operator, the system of wireless power transfer for an electric vehicle (EV) are demonstrated as follows,

The system of wireless power transfer for an electric vehicle (EV) consists of primary coil on the surface of the road to transfer the electric energy and secondary coil on the electric vehicle to pick up the transferred power wirelessly. The alternating electric current is supplied to the primary coil to create alternating magnetic flux which will induce electromotive force in the secondary coil to charge the battery on the electric vehicle which will be supplied to the electric motors as in Fig. 2.

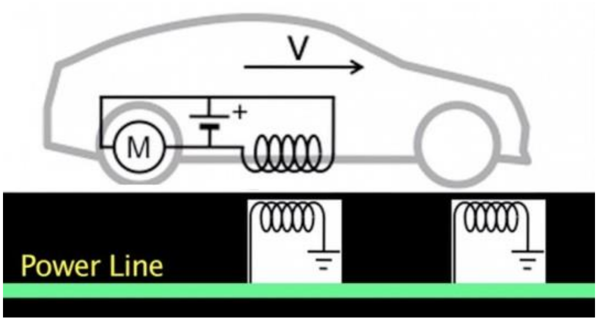

Fig. 2 System of wireless power transfer for an electric vehicle (EV) (Source: Stanford University [18])

The problem is identified as the inefficient useful function of inducing electromotive force. The initial substance-field model can be created as in Fig. 3, with Magnetic Field interacts with Primary Coil as Tool (S2) and Secondary Coil as object (S1) to induce inefficiently electromotive force on Secondary Coil.

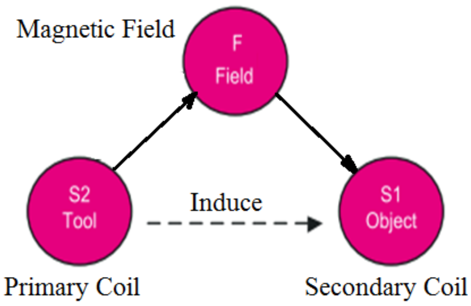

Fig. 3 Initial substance-field model of insufficient useful function (Based on the model of systematized Su-Field Analysis by Iouri Belski [10])

The MAR Operator is deployed and the ideas are generated as in Table 3.

Table 3

The MAR Operator and Ideas generated for improving wireless power transfer

The MAR Operator	Component manipulated	Ideas generated
Modify	Field	1. Use high frequency of Alternating Current 2. Use resonance frequency
	Substance	3. Divide primary coil into multiple sets of coil
Add	Field	-
	Substance	4. Insert ferromagnetic material between the 2 coils
Replace	Substance and Field	5. Replace the system with solar cell using solar energy

The ideas generated are actually applied and under research by many institutes [18,19]. Fig. 4 shows an example of multiple sets of coil.

Fig. 4 Example of multiple sets of coil (Source: University of Tokyo [19])

The high frequency of Alternating Current and resonance frequency have also been applied to improve the efficiency of the wireless power transfer system, but the humming noise from the electromagnetic vibration of the coil due to high frequency of Alternating Current is very annoying. The problem can be regarded as harmful effect as displayed in the initial substance-field model in Fig. 5.

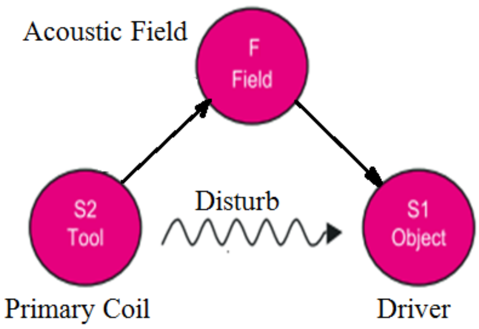

Fig. 5 Initial substance-field model of harmful effect (Based on the model of systematized Su-Field Analysis by Iouri Belski [10])

The MAR Operator is deployed and the ideas are generated as in Table 4.

Table 4

The MAR Operator and Ideas generated for Eliminating the Noise

The MAR Operator	Component manipulated	Ideas generated
Modify	Field	-
	Substance	1. Modify the structure of the coil to unmatch the resonance frequency
Add	Field	2. Use another acoustic field with same frequency but inversed phase to kill the noise
	Substance	3. Add shielding chamber to contain the noise
Replace	Substance and Field	4. Replace the system with solar cell using solar energy

From the above case studies, the MAR Operator has demonstrated its effectiveness for idea generation. With the hints from MAR Operator, the problem solvers who are usually subject matter experts can easily come up with practical ideas within a short time. It relieves problem solvers, especially TRIZ beginners, from the burden of going into the details of the system of standard solution which is complicated and takes time to learn. After the problem solvers become acquainted with the system of standard solution, they can use the MAR Operator to create initial solution concepts and then refine the solutions for more ideal ones with class 3 and class 5 of the system of standard solution.

5. Conclusions

The MAR Operator which consists of 3 suggestions for Modifying, Adding, and Replacing the component (substance and/or field) of the system is proposed in this paper with the purpose to generate ideas for improving the useful function and/or eliminating the harmful effect of the system. It was developed from the analysis and compilation of suggestions in each standard solutions of class 1 and class 2 of the system of standard solutions and has been demonstrated with case studies to show it effectiveness in idea generation for solution concepts. The MAR Operator is aimed to facilitate problem solvers, especially TRIZ beginners to get started using TRIZ. It is not intended to replace the entire System of Standard Solutions. After the problem solvers become acquainted with the system of standard solution, they can use the MAR Operator to create initial solution concepts and then review or refine the solutions for more ideal ones with the original system of standard solution. Besides, in the situation where "fast" is more important than "thorough", the MAR Operator can be easily applied. Hence, it can be used to solve the problem model in the Part 1 (step 1.7) of ARIZ (Algorithm of Inventive Problem Solving) as the goal of this part is for refining the understanding of the problem rather than solving the problem.

Acknowledgements

The author would like to express his grateful thanks to Thai-Nichi Institute of Technology for their support in this research project, and also to TRIZ Master Len Kaplan for his kind advice.

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TRIZ*fest* 2015

STATISTIC STUDY OF AN ALTERNATIVE WAY TO FORMULATE A PAIR OF ENGINEERING CONTRADICTIONS SO AS TO SEEK FOR SOLUTIONS WHICH SATISFY THE CONTRADICTORY REQUIREMENTS OF ITS EQUIVALENT PHYSICAL CONTRADICTION

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Abstract

A systematic study of the inventive problems from the Altshuller book “And suddenly the inventor appeared”, proves the statistical validity of the alternative formulation (actually two formulations) of a pair of engineering contradictions so as to seek for solutions which satisfy the contradictory requirements of its equivalent physical contradiction. A novel categorization of pairs of engineering contradictions emerges from this study and is related to the estimated usefulness of this alternative formulation.

Keywords: alternative problem formulation, pair of engineering contradictions, physical contradiction, satisfaction, statistical analysis, thinking pathway

1. Objective of the study

The primary objective of the present study is to check the correctness of the novel approach (as proposed in [1]) to reformulate a pair of engineering contradictions, so as to seek solutions which satisfy the contradictory requirements of its equivalent physical contradiction (note: for the sake of simplification, in the rest of the article, one will speak of “solutions which satisfy its contradictory requirements / contradictory requirements of the pair of engineering contradictions”, even if it is not strictly correct to say so).

2. Main findings and definitions from the former article

In the present chapter the main findings and some definitions from the former article [1] are summarized.

Any pair of engineering contradictions (EC1, EC2) can be expressed as follows (where F1 high and F2 high are both wished):

$$\begin{cases} \text{EC1: If P is low, then F1 is high, but F2 is low} \\ \text{EC2: If P is high, then F2 is high, but F1 is low} \end{cases}$$

If one considers (for example) the individual engineering contradiction EC1 and its causal character (P low causes F1 high and P low causes F2 low), then EC1 can be re-formulated as:

Φ1: How to obtain F2 high while maintaining P low?

This formulation is made possible because maintaining P low causally ensures F1 high, therefore the F1 high requirement has disappeared from the reformulation. One defines similarly Φ2, the respective re-formulation of the individual contradiction EC2:

Φ2: How to obtain F1 high while maintaining P high?

The equivalent physical contradiction ePC (equivalent to (EC1, EC2)) is defined as: P must be low so that F1 is high, and P must be high so that F2 is high. It has been shown that resolving Φ1 and Φ2 is corresponds to the resolving of ePC by means of satisfaction of its contradictory requirements (F1 high, F2 high).

3. Experimental method

First it has been necessary to select a list of solved inventive problems which is statistically representative of inventive problems that the TRIZ practitioners encounter. One of the best ways to obtain such a list could have been to randomly select a sufficiently large, given number of patents in a large patent database (e.g. that of the US Patent Office), to analyze them, to extract one or several pairs of engineering contradictions that have been solved (if possible). Such a work would have been very tedious and long, for multiple reasons. Finally, as pragmatic alternative, all the educational, inventive problems from the book "And suddenly the inventor appeared" from G. Altshuller have been considered for this study.

Second a step-by-step analysis of each inventive problem from the chosen set has been performed as follows:

1. Determine if the inventive problem is exploitable for this study; for example, some problems weren't exploitable because G. Altshuller gave no control solution;
2. Attempt to express the inventive problem as one single pair of engineering contradictions, the general form of a pair of engineering contradictions (EC1, EC2) being: $\left[\begin{array}{l}\text{EC1: If P is low, then F1 is high, but F2 is low}\\ \text{EC2: If P is high, then F2 is high, but F1 is low}\end{array}\right.$
3. Determine whether the control solution satisfies the contradictory requirements (F1 is high and F2 is high) of the equivalent physical contradiction ePC; if not, determine if the control solution corresponds to the separation of the contradictory requirements, or to their bypass;
4. If the control solution (if several control solutions exist, one of them is chosen) satisfies the contradictory requirements, check if, from the two proposed possibilities Φ1 and Φ2, one of these problem formulations is correct with regards to the control solution, i.e. could have been used to find the control solution.

4. Results

4.1. Statistics of inventive problems

The statistical analysis of the chosen set of inventive problems gives following results:

1. From all inventive problems considered, 77 have been considered as exploitable for this study;
2. 18 problems from these 77 could not be easily expressed as pairs of engineering contradictions;

3. 59 problems from these 77 could be expressed as pairs of engineering contradictions, either directly from the problem formulations, or with some additional work, taking into account some elements given in the text of the problem;

4. For 13 pairs of engineering contradictions from these 59, their respective control solutions do not correspond to the satisfaction of "their" contradictory requirements:

    a. For 7 pairs of engineering contradictions from these 13, their respective control solutions correspond to the bypass of their contradictory requirements

    b. For 6 pairs of engineering contradictions from these 13, their respective control solutions correspond to the separation of their contradictory requirements (3 in time; 1 in space; 1 in both hierarchical level and time)

5. For 46 pairs of engineering contradictions from these 59, their respective control solutions correspond to the satisfaction of their contradictory requirements

For these 46 pairs of engineering contradictions, it is found that 100% of them could have been reformulated as one of the two alternative problem formulations proposed in [1] (Φ1 or Φ2), so as to help finding their respective control solutions.

4.2. Further analysis

This statistical study has revealed some additional findings, with regards to the alternative formulation of the former 46 problems.

Actually a categorization of pairs of engineering contradictions and of their alternative formulations emerges:

1. 33 pairs of engineering contradictions are of the following type:
   EC1: If action A is done / technology T is used, then F1 is high, but F2 is low
   EC2: If action A is not done / technology T is not used, then F2 is high, but F1 is low

   These pairs of engineering contradictions can be qualified as binary (0/1). Among these 33 engineering contradictions:

    a. 19 have their respective control solutions corresponding to the following alternative problem formulation Φ2: how to obtain F1 high while action A is not done / technology T is not used? This alternative problem formulation can be called absence-related. Example: How to measure the amount of gas without breaking the bulb? (page 4 of [2])

    b. 14 have their respective control solutions corresponding to the following problem alternative formulation Φ1: how to obtain F2 high while action A is done / technology T is used? This alternative problem formulation can be called presence-related. Example: How to make accurate holes while drilling the rubber hose? (page 11 of [2])

2. 2 pairs of engineering contradictions could be (as an alternative to mere binary pairs of engineering contradictions) expressed as contradictions between alternative systems [3] (also called alternative contradictions); in that case it is possible to propose the (adapted) alternative formulation Φ1': how to obtain F2 high with system S1? Conversely, Φ2': how to obtain F1 high with system S2? Example: How to avoid any

additional damage to the emergency landed airplane while the airplane is transported by rolling?

3. 11 pairs of engineering contradictions which are no alternative contradictions and no binary contradictions. The form of these pairs of engineering contradictions is more conventional. However, there are differences between them:

   a. 5 of them can be qualified as discrete (ex.: 1/2; 1/many; with property L/with property non-L). Example: How to eliminate any risk to hurt the scout while the scene (of Robin Hood) is done in one shot? (page 129 of [2]).

   b. 6 of them can be qualified as continuous (ex.: few/many; high/low) (in practice few/many approaches the continuity thanks to big numbers considered, while high/low is really continuous). Example: How to manufacture at low cost small metallic particles? (page 70 of [2]).

   In each case, the forms of the two alternative problem reformulations Φ1 and Φ2 are conventional and can be considered as symmetrical, contrarily to the binary pairs of engineering contradictions.

5. Usefulness of the alternative problem formulation

It is not obvious to estimate the usefulness of reformulating a pair of engineering contradictions as proposed in [1]. First a wider statistics of inventive problems should be studied so as to be more representative of most usual situations faced by the TRIZ practitioner. Second this statistics should not only be built ex-post, as in the present study, but it should be built on the practice of several TRIZ practitioners in numerous real innovation or problem solving projects: this is the usual practice for testing a new tool or a new algorithm in the TRIZ community.

From the limited statistics used in the present study, however, it is possible to draw some trends and discuss them:

1. The absence-related alternative problem formulation for a binary pair of engineering contradictions incites to seek for other actions / other technologies (than the current action / technology) which allow F1 high. Consequently this incites to apply Scientific Effects and FOS (Function-Oriented Search). Conversely it gives no hint in advance about which from the sought actions / technologies can also bring F2 high. Consequently this formulation gives only one direction of seeking which turns out to be wide, and nothing more. Consequently in that case the alternative formulation is not very useful beyond giving a wide direction of thinking.

2. The presence-related alternative problem formulation for a binary pair of engineering contradictions incites to seek a way to obtain F2 high while action A is done / technology T is used. As explained in [1], the causal approach to one member of a pair of engineering contradictions gives a good chance that F1 high is conserved, because F1 high is caused by the fact that action A is done / technology T is used. In other words, as action A / technology T brings F1 high, there is a high probability that an attempted modification to obtain F2 high keeps F1 high. The same kind of mechanism is at work while performing a Feature Transfer between two alternative systems. It is observed that the same mechanism is at work for any of both alternative formulation of a pair of discrete or continuous engineering contradictions. As a consequence, all these alternative problem formulations of a pair of engineering contradictions (when seeking solutions that satisfy their

contradictory requirements) are more acute, and help the TRIZ practitioner to better express the initial problem so as to seek a part of the possible solutions in the right direction. As such, in these cases, it constitutes a real TRIZ heuristic. Finally it is estimated by the author that this heuristic is more or less useful, depending on the inventive problem at hand with (at the end, if any) a control solution that satisfies the contradictory requirements of F1 high and F2 high.

Finally the author estimates the statistical usefulness of this heuristic U for different kinds of pairs of engineering contradictions as above categorized, as follows:

U(absence-related binary) << U(presence-related binary) < U(alternative (systems)) < U(discrete and continuous)

6. Applications

6.1. For a pair of engineering contradictions

When attempting to solve of a pair of engineering contradictions by means of the Altshuller matrix or the complete list of the 40 inventive principles, one major disadvantage (as identified by the author) is the lack of clarity due to the mixing of different solving directions: considering the equivalent physical contradiction (as defined in [1], which is not necessarily the physical contradiction as defined by G. Altshuller in ARIZ-85C), the different sought solutions corresponding to satisfaction, separation and bypass of the contradictory requirements are all mixed together. Therefore, for seeking solutions which satisfy the contradictory requirements of the pair of engineering contradictions at hand, two alternative formulations can be used. This can be done while keeping in mind the statistical usefulness of this heuristic (see the end of the former chapter) as related to the category of the pair of engineering contradictions at hand. It is possible to use this heuristic as a complement to the Altshuller matrix or the list of 40 inventive principles. However, relatively often, as experienced by the author in his project execution and group facilitation practice, the heuristic helps reformulating the inventive problem in such an acute and precise way that the use of the former classical TRIZ tools is unnecessary (as it may happen when applying the Ideal Final Result, for instance). Of course, it is still possible, whatever the result, to look for a/the (really) physical contradiction underlying the pair of engineering contradictions, and try to solve it, or even to apply ARIZ if necessary.

6.2. For a physical contradiction

For a physical contradiction, the same heuristic can be used to seek solutions which satisfy the contradictory requirements. The only preliminary work is to build the equivalent pair of engineering contradictions (as explained in [1]). Then the reformulations Φ1 and Φ2 can be used.

For a physical contradiction or a pair of engineering contradictions, in addition to the proposed heuristic, its causal counterpart [1], where one member of a pair of engineering contradictions is expressed and expanded as a causal chain of causes and effects, can also be used.

7. Conclusions

This study has shown that the alternative formulation of a pair of engineering contradictions (Φ1 and Φ2) so as to seek for solutions which satisfy its contradictory requirements, as defined in [1] and as reviewed in chapter 2, is statistically valid. From this statistical analysis a categorization of the typical pairs of engineering contradictions emerges. This categorization in binary, alternative (already existing), discrete and continuous pairs of engineering contradictions allows estimating the statistical usefulness of the proposed heuristic.

In practice it means that a lot of solutions which satisfy the contradictory requirements of a pair of engineering contradictions can be found by the complementary use or sole use of this heuristic.

From a more theoretical point of view, the findings in the study show the relevant character of the graph (proposed in [1], see Fig. 1) below showing two different thinking pathways (dotted arrows) to solve individually one member (EC1) or the other member (EC2) of a pair of engineering contradictions. These pathways are exactly related to the alternative problem formulations Ф1 and Ф2 studied in the present article. Finally it is hypothesised that the asymmetry of the Altshuller matrix is related to the difference of these two pathways, the bypass and the separation of the contradictory requirements (of the equivalent physical contradiction) being symmetrical by nature.

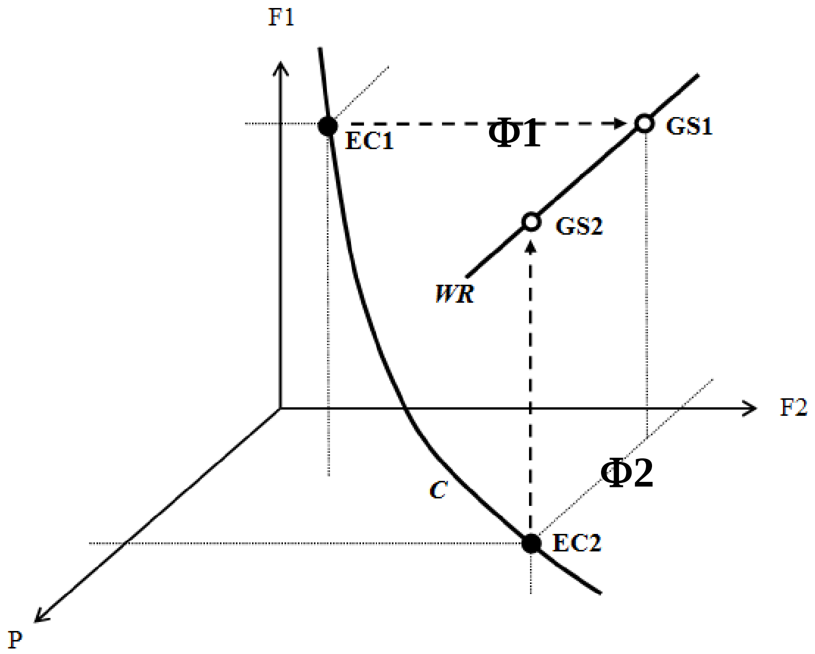

Figure 1: Pair of engineering contradictions in 3D-diagram (continuous representation) with coordinates system (P, F2, F1) which shows the two different thinking pathways (dotted arrows) leading to different types / groups of solutions GS1 and GS2 [1]. GS1 and GS2 correspond exactly to the solutions obtained when using the two alternative problem formulations Ф1 and Ф2 studied in the present article

Note

On written or oral demand, the author can provide the table of the inventive problems considered in this study and the corresponding analytical results, as exposed in the present article.

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TRIZ*fest* 2015

SYSTEMATIC BUSINESS INNOVATION: A ROADMAP

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Abstract

Since 1956, TRIZ has been gradually evolving to bridge all sorts of gaps between a systematic approach and seemingly random creative innovation: from solving specific problems to systems analysis and forecast of future generations of technical products and technologies. In the early 1990s, the first attempts were made to use the core paradigm of TRIZ to explore if a systematic approach can be used to innovate within the areas of business and management [1]. Although the overall number of such attempts have been considerably lower than within technology and engineering, the experience gained during past dozen of years of applying TRIZ to business and management helps with drawing conclusions which parts of TRIZ can be directly used in the areas of business and management; which parts still have to be adapted; and what kind of new knowledge is needed to enable a systematic approach to business and management innovation. The paper attempts to structures business innovation tasks and summarizes the author's experience.

Keywords: TRIZ, business innovation, systematic innovation.

1. Value Business Innovation

1.1. Types of Technology and Business Innovation

The first question which has to be clarified is what is business innovation? In technology, the word "innovation" means a *new* solution which has proven its feasibility and has been successfully implemented. One of the key criteria of distinguishing a technology innovation from other types of solutions is that an idea which forms a basis of an innovative solution is new and it can be confirmed by the fact that the solution was patented. Usually patentability of a solution proves its novelty, even despite the fact that the idea could have failed its successful implementation or even failed to work at all.

There are no patents in the business world; and therefore the word "innovation" can be understood with a much a broader meaning than in technology and engineering. Nevertheless, just like in the technology and engineering, one might assume that a business innovation is a solution which has never been used within a certain specific context: either it is a new business value proposition, or a new business model, or a new way of organizing a specific business process or activity. In fact, a certain solution could have been known for years within one market niche but its adaptation to a different market niche creates innovation. For example, Coca Cola was invented as a medicine but later was introduced as an innovation for the non-alcoholic refreshment drinks market. Selling the same product within a different context thus became innovation.

In general, a scope of business and management innovation is broader than within the technology. Business innovation belongs to a supersystem while both technical and non-technical products are systems or subsystems. Classical TRIZ presents two main categories of technology-related innovations:

1. *Innovation of a technical product* (also known as a "technical" or "engineering" system). It can result from disruptive change of product's quality, performance, composition, as well as from drastic cost reduction or replacement of a basic physical principle (underlying technology) which makes it possible to deliver the functionality required. Innovation of a technical product can also address adaptation of already existing product to a new market (e.g. technology diversification).
2. *Innovation of a process* which results in the development and production of a technical product: in other words, innovation of production or manufacturing. As obvious, such a process includes a range of other technical products to enable its key operations.

A more detailed classification of innovative tasks for technology and engineering is provided in [2]. In the business and management environments, innovation can apply first, to how a business is organized, and second, how the same business is managed. Although there are known attempts to classify business innovation tasks, for example in [3,4] we believe that such classifications are still non-exact and overlapping because they are not based on a system approach.

An approach to business innovation structuring and roadmapping presented below is based on over 60 practical cases performed by the author since 2003 and studies of over 1000 cases of business innovation in diverse fields. These studies resulted in a better understanding how TRIZ can be used for business innovation [5].

First, one can distinguish between the following six large areas of business and management innovation:

1. *Innovation of value proposition*. This type of innovation is the same as innovation within technology and engineering since we deal with a value proposition which always includes at least one main ingredient: a tangible (physical) or an intangible product (e.g. service), or a combination of tangible and intangible products. For example, the value proposition of an automotive company can be based on the combination of delivery of a car, its service and insurance. A value proposition of a training company can be based on the combination of delivering a training course and its follow-up support.
2. *Innovation of a business process*. A typical business process consists of a sequence of more specific actions and activities. In a modern business organization, their structure is usually rather well defined. A business process can be considered similar to a production processes in the technology domain.
3. *Innovation of a business system*. A business system consists of a number of critical components which support business processes and create value which is then brought and maintained at either B2B or B2C markets. The components of a business system include tangible and intangible assets, which belong to the system and directly contribute to the shareholder value of the system.
4. *Innovation of a value network*. Due to broad expansion of businesses to supersystem, value networks have become increasingly popular. While in the past almost any business could be represented by a value chain (both within the organization as well as on a broader scale), where each step adds value from a supplier towards a customer within the chain-like structure, today value creation can be represented through

network structures and might involve non-commercial components: customers, social and government bodies, etc.

5. *Innovation of a business model*. Business model innovation becomes very popular today and affects all other types of business innovation [6]. However it is important to recognize the difference between a business system, value network, and a business model. Recently, a number of different approaches have emerged to identify a business model: some only focus on the ways specifying how revenue is generated and distributed but other approaches might include all the components of a business system, value proposition, and supplier/partner/customer relationships as well. In other words, when we consider business system/network innovation we focus on the components change while when we focus on business model innovation we primarily change the relationships between the components of a business system and its supersystem. Thus, there can be two situations: a) a business model is encapsulated within a particular single business system (organization) and matches the business system architecture, and b) a business model expands beyond the business system.
6. *Management innovation*. This particular category covers those innovative solutions which deal with management and control of systems and processes to create and deliver value in the most effective and efficient ways. Those can be business systems, business models, value chains and value networks.

In the rest of the paper we will focus on the first 5 categories of value business innovation since as follows from the author's experience management innovation requires separate consideration. We will identify specific tasks which can be distinguished within each category of business innovation and show how these tasks can be supported with relevant TRIZ tools.

2. Typical Tasks of Value Business Innovation

When triggering an innovation activity, a business organization usually faces two types of ininital situations:

1) A specific challenge is known and is expressed in terms of a specific problem (challenge) which can not be solved by known methods. For example, a company is willing to expand its products portfolio, or drastically cut costs of a specific business process but the existing methods do not help with reaching the targets desired.
2) A specific challenge is not defined yet, a company just wants "to innovate" to grow or to create competitive advantage. Such goals are too general and need to be decomposed to clear sub-goals.

Our experience shows is that both situations occur very regularly at all types of business organizations. While in the first case TRIZ can be directly used in a structured way to approach a clearly defined challenge and establish a process of moving from a problem to generating and evaluating solution ideas, the second situation requires definition and clarification of both final and intermediate goals. Therefore it would be of help to any organization to have a map of all possible opportunities for business innovation.

In this chapter we will introduce typical tasks of value business innovation with respect to each category presented in the previous chapter and illustrate these task with the examples drawn from business innovation within a company delivering training services. It is important to note that a) only most significant tasks from our perspective were included and b) some tasks can overlap since they might belong to a number of categories.

2.1. Typical tasks: Value Proposition

Value proposition is a sum of benefits a prospect is believed to obtain after purchasing a product, either tangible or intangible one or their combination. Therefore, the value proposition is based on the properties, parameters and features of a product itself. Table 1 shows typical tasks with examples which result in innovative solutions applied to a product. Note that this approach is valid for products that have functional meaning within the context of the functional use of the product. The vast majority of products are intended to be used within the context of their functional use. Exceptions are products created for a non-functional use, for example works of art.

Table 1

Typical innovative tasks for value proposition innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Eliminating misinterpretation of the course content.
2	Increase performance: increase value of key parameters.	Adding new content of a particular course without losing quality and creating demand for extra learning time.
3	Reduce “dimensions” of a product: physical volume, information volume, time taken by processes.	Making a training course considerably shorter without losing content and quality.
4	Improve user experience.	Making working with practical examples more engaging by using their own cases.
	Create new user experience.	Move training outside a class room to the real-world domain.
5	Radically change shape (for physical products) or reorganize structure (for intangible products)	Segmenting the course modules to make learning more effective.
6	Add new functions and features.	Adding “walk-through” case-based training experience.
7	Radically decrease cost: purchasing price, total cost of ownership.	Drastically cutting cost of training per person.
8	Transfer the existing product principle (technology) to a new market.	Using the existing training model for training new subjects for new markets.
9	Create a radically new product, a new product generation, or a new product line (including forecast).	Launching distant training.

2.2. Typical tasks: Business process

Table 2 identifies a set of typical tasks for innovative change of business processes.

Table 2

Typical innovative tasks for business process innovation

	Typical Task	Example

1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Eliminating miscommunication between a training company and a prospect within the customer acquisition process.
2	Increase performance: increase values of key performance parameters.	Serving increased number of prospects without extra cost and time.
3	Reduce a number of activities in a process.	Reducing ordering process to a “one-click” purchase of the courses.
4	Reduce a number of processes.	Merging processes of acquisition and introductory training.
5	Add new functions and features to the existing process.	Providing prospects with extra information in time on demand.
6	Radically decrease cost of a process.	Drastically decreasing cost of acquiring a new customer.

2.3. Typical tasks: Business System

Table 3 represents typical tasks for business system innovation.

Table 3

Typical innovative tasks for business system innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Decrease risks by leasing training rooms rather than purchasing new property.
2	Increase performance: increase values of key performance parameters.	Increasing rate of business development to search for new business partners.
	Radically decrease cost of a business system.	Decreasing cost of operating a specific business unit.
3	Reorganize for a new market or a new value proposition	Transformation of management structure from hierarchical to matrix
6	Merge two or more business systems.	Acquiring a company which provides complementary training.
8	Generate a spin-off business.	Starting a spin-off company to distribute products in addition to training.

2.4. Typical tasks: Value Network

If a business model focuses primarily on the functional relationships, a value network is a system of interrelated components which together create value, generate and maintain revenue streams. Often it is not easy to separate between a value network innovation and business model innovation. The primary goal of value network innovation is to identify how new value can be obtaining from the existing members of the value network or how to discover new members to produce added value.

Table 4

Typical innovative tasks for value network innovation

	Typical Task	Example
	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Synchronizing similar types of training curricula to avoid confusion.
	Increase performance: increase values of key performance parameters.	Use trainers on different continents to handle time zone differences.
	Discover new value partners	Turning customers to licensed trainers.
	Innovatively optimize the existing network	Reducing travel costs by widely using videoconferencing.
	Reduce bottlenecks in the existing network	Lowering entering barrier for new customers through value-adding collaborations with partners
	Create a new value network	Launching a virtual aggregated training facility based on the network of independent vendors.

2.5. Typical tasks: Business Model Innovation

The table below presents only those tasks which do not directly relate to value proposition and business system itself.

Table 5

Typical innovative tasks for business model innovation

	Typical Task	Example
1	Increase quality and reliability: reduce impact of negative factors, eliminate negative and undesirable effects, decrease fragility, volatility and variability.	Asking a community to provide feedback on the training material (for bonuses)
2	Increase performance: increase values of key performance parameters.	Introducing "full immersion" training.
3	Increase scalability.	Introducing a franchising model.
4	Increasing market size/share.	Localizing the courseware and attracting local native speakers as trainers.
5	Restructure "system-supersystem" relationships	Outsourcing courseware development to a third party.
6	Introduce new revenue streams	Reselling related products from third parties
7	Introduce new offerings.	Creating and distributing new low-cost video tutorials
8	Radically decrease cost.	Licensing new material from third parties rather than developing own materials
9	Introduce a radically new business model.	Introducing a new model of payment through royalties based on from future customer's revenue.

2.6. Evolution of business systems

By studying a process of business models evolution it becomes obvious that in general the process of evolution matches the S-curve model of technical systems evolution and the other TRIZ trends (Fig. 2). Two parallel trends have been especially observed: 1) Transition to supersystem and 2) The growth of the degree of segmentation of business systems and components.

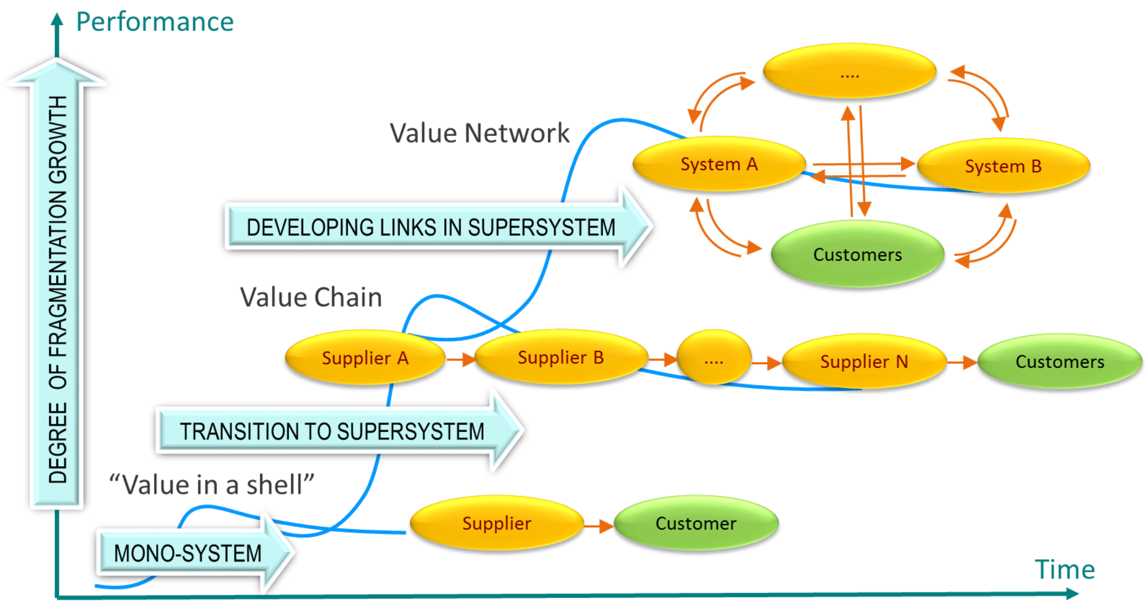

Fig. 2. Typical evolution of a business system: from a mono-system creating value and delivering it directly to customers towards network poly-systems with developed links and growing degree of segmentation

A deeper understanding of details of such an evolution model will help to make better descisions by business innovators regarding next steps of evolving their business systems.

3. A Systematic Roadmap

3.1. TRIZ Process to Support Business Innovation

As follows from an overview of typical innovative tasks shown above, there are three large conceptual groups of innovative tasks in each category:

a) tasks dealing with solving specific innovative problems,

b) tasks related to the overall system / value network innovative redesign, and

c) tasks related to extracting new market opportunities for innovation.

TRIZ proposes a systematic approach to deal with each group of tasks. A typical stage-gate front-end innovation process is shown in Fig. 1. This process does not depend on what conceptual group is involved.

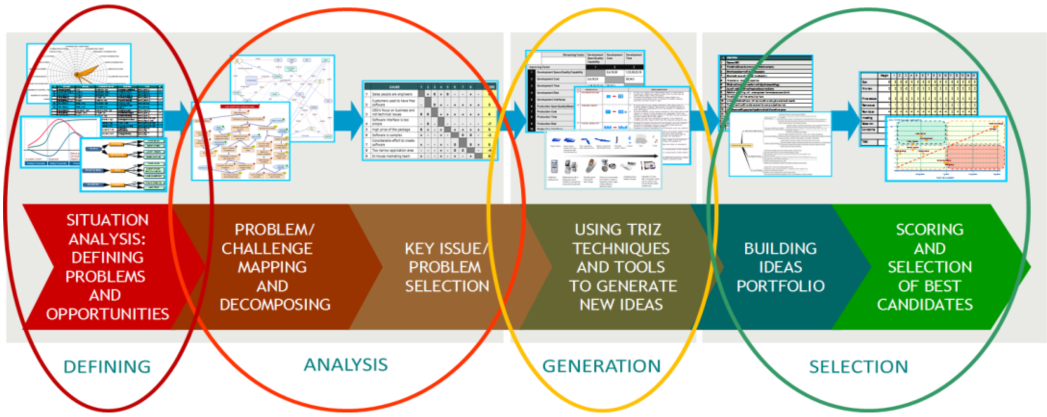

Fig. 1. A typical stage-gate process with TRIZ

A process of dealing with every type of innovation tasks includes four main steps where each step is supported with specific TRIZ tools adapted for business innovation [7, 8]:

1) Defining, where goals are identified and revision of demands and constraints is performed.

2) Analysis, where analytical tools are used to structure a situation, build its model, decompose a challenge identified and extract key problems/ specific challenges.

3) Ideas generation (including problem solving), where a list of new innovative ideas are generated.

4) Evaluation, where the most promising solution candidates are ranked and selected.

An example of such a process with the use of modern TRIZ tools to help with systematic business model innovation based on the Business Model Canvas approach [9] can be found in [10].

3.2. Tasks, Stages, and Tools

The size of this paper is too limited to present a process for each task mentioned in section 2, therefore some types of tasks were grouped. Table 6 shows a summary of the tools which are most relevant for different groups of tasks. This classification is based on the experience of the author and his network being engaged to assisting customer business innovation since 2003. The table only includes analytical and ideas generation stages, since evaluation stage uses almost the same tools to select most promising candidate solutions and roadmap them: Multi-Criteria Decision Matrix, Ideality Criteria, Ideas Landscape Chart.

Table 6

Summary of the TRIZ and Systematic Innovation tools supporting analytical and creative stages of different tasks of business innovation.

Generic task	Where to apply	Analytical Stage	Ideas Generation
Increase quality and reliability (reduce negative effects).	Value Proposition; Business System; Business Process; Business Model; Value Network	Problem perception network mapping; Root-Conflict Analysis (RCA+); Function Product /Process Analysis	40 Inventive Principles; ARIZ (+Knowledge bank); Trends of Business Systems Evolution
Increase performance (improve positive effects).	Value Proposition; Business System;	Problem perception network mapping; Root-Conflict Analysis	40 Inventive Principles; ARIZ (+Knowledge

	Business Process; Business Model; Value Network	(RCA+); Function Product /Process Analysis	bank); Trends of Business Systems Evolution
Radically decrease cost.	Value Proposition; Business System; Business Process; Business Model; Value Network	Function Product /Process Analysis	Trimming; Trends of Business Systems Evolution.
Reduce “dimensions”: (physical volume, information volume, time).	Value Proposition; Business System; Business Process; Business Model	Function Product /Process Analysis	Trimming; Trends of Business Systems Evolution.
Transfer the existing principle to a new area.	Value Proposition; Business Model	“ZIRT”: inverse TRIZ	Inverse Function-Oriented Search; Catalogue of business models
Reduce bottlenecks	Business Process; Business System; Business Model	Flow Analysis	40 Inventive Principles; ARIZ (+Knowledge bank);
Increase scalability.	Business Model		Trends of Business Systems Evolution; Catalogue of business models
Create a radically new system.	Value Proposition; Business System; Business Process; Business Model; Value Network	Value-Conflict Mapping; Multi-Screen Analysis; Technology and Business Roadmapping; Main Parameters of Value	Trends of Business Systems Evolution; Catalogue of business models ARIZ (+Knowledge bank)
Improve or create user experience	Value Proposition; Business Model.	Functional Needs Assessment; Value-Conflict Mapping; Main Parameters of Value	Trends of Needs and Demands Evolution
Introduce new revenue streams	Business Model.	Value-Conflict Mapping;	Trends of Business Systems Evolution
Reorganize for a new market or a new value proposition	Business System; Business Process; Value Network.	Value-Conflict Mapping;	Trends of Business Systems Evolution

Conclusions

At this moment, applications of TRIZ in the areas of business and management are rather limited. Partly it is due to the fact that TRIZ and Systematic Innovation have been developed within an engineering community and their applications outside technology are not very well known. On the other hand, direct application of TRIZ tools developed for technology innovation is not always well received by the business audience due to a different language, and therefore adaptions are needed.

Nevertheless, there is already some positive experience with adapting TRIZ tools to business needs (such as reformulation of inventive principles, inventive standards, ARIZ), structuring innovative business tasks, and using the tools of TRIZ to support the process of business innovation. Still, a broader research and development activities are needed to bridge the gaps between various innovative tasks mentioned above and supporting systematic tools.

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TEACHING, LEARNING & APPLYING TRIZ IN UNIVERSITY

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Abstract

This research proposes a new approach towards teaching innovation skills to university students. A new subject is developed using a proposed elements of innovation in education framework. The framework highlights the need of having a proven methodology and also the need for motivation behind the process of innovating. All of the students are expected to develop a new conceptual innovation that solves a common everyday problem. TRIZ tools are taught to the students to complete the project. To motivate the students to do well, marks are allocated for their project. Besides that, a competition for their project is held at the end of the semester to motivate the students to do better than their peers. Their final exam is structured to test their knowledge of the TRIZ tools. In the pilot semester, first year 91 university students from technical and non-technical faculties enrolled in this subject. The outcome is the development of 15 novel and innovative concepts. Feedback from the students in regards of the subject's contents, delivery, and effectiveness is gathered through surveys. The average grade of distinction achieved by the students for their project and final exam signify the deep understanding of the theoretical and application aspects of the TRIZ tools.

Keywords: TRIZ, Education, Innovation Skills, New Concept Development

1. The Skills Gap

The world is fast changing in this innovation era. New discoveries lead to new technologies. New technologies lead to new industries. Finally new industries lead to the demand of new practices in the form of job skills. The workplace is shifting from being knowledge based to skills based. This shift is evident with the latest demands of skills by the workplace.

Specific knowledge and relevant work experience which once was high on demand has now become less in demand. What is currently high on demand are skills such as creative problem solving and strategic thinking, and analytical thinking. These skills are innovation related. As shown in Figure 1, general thinking skills are desired more than specific knowledge and work experience.

Education have to be of relevance to the students and to the workplace. It is not enough to equip students with knowledge which wears off with technological trend. They need to be equipped innovative skills as well to not only survive in the competitive workplace but to thrive in it.

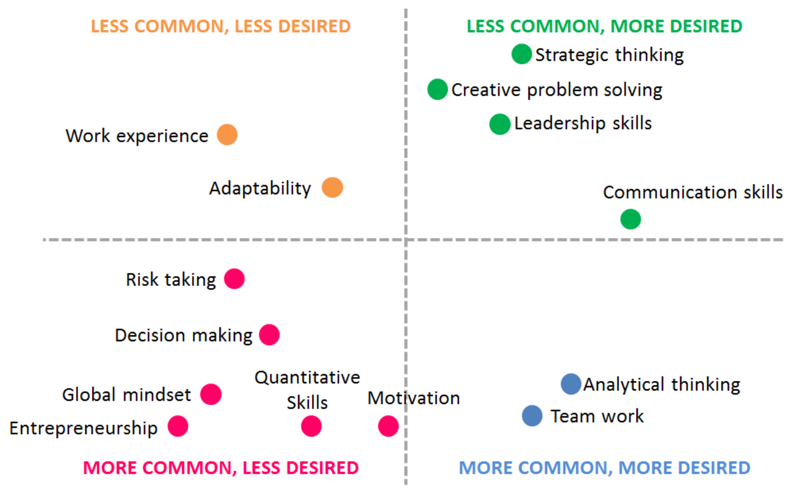

Fig. 1. Desirability of Employee Skills by Employers (Levy & Rodkin, 2015)

This research proposes the development of a new teaching approach that equips students with innovation skills. A new subject is developed to have the students learn, understand, and apply skills to develop novel innovations.

2. Elements of Innovation in Education Framework

This research introduces the concept of motivation and methodology into the teaching innovation. To develop an innovation, it is proposed that three elements are needed. These elements as illustrated in Figure 2 are the presence of the innovators, the proven innovation methodology, and the motivation behind the process of innovating.

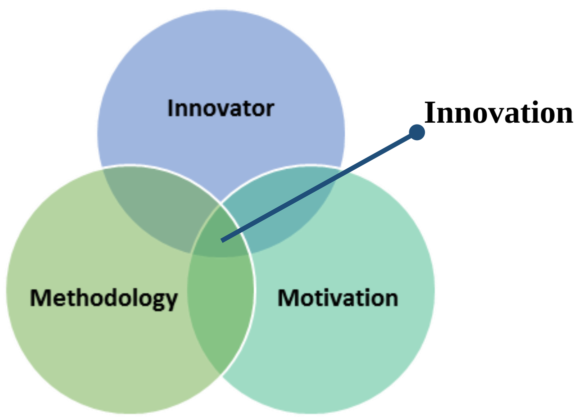

Fig. 2. Elements of Innovation in Education Framework

The first hurdle in achieving innovation is to get a reliable method. Without a method, students will embark on a trial and error approach. Such approach relies too much on human psychological factors which often lead to disorderliness (Jiang et al. 2013). It is common to have the students undergo projects within their studies. However, most students were still graduating from their studies without a clear understanding of the methodology used to solve those projects (Kitto, 2000). Instead of relying on trial and error methods to develop innovation, a more structured and reliable approach is needed.

The Theory of Inventive Problem Solving which is widely known as TRIZ is a methodology that consists of inventive problem solving tools. Through successful industrial case studies, these tools have been proven to be effective in developing innovations repeatedly. Therefore, TRIZ is chosen to form the basis of this subject. The classic TRIZ framework is used where there is the generalizing of problems and solutions. Most of the classical TRIZ tools are covered in this subject.

Predominantly, TRIZ is mainly taught to only the technical students as it is engineering-oriented. Because of that, the tools of TRIZ are also known to be too complex for understanding and practical application. Complex tools hinder learning (Tsai & Chen, 2012). Through this research, the proposed delivery approach is structured to suit the learning by students of technical and non-technical background.

It is common to teach TRIZ through projects. Students are encouraged to learn TRIZ by applying the tools on projects. The projects can either be self-chosen (Jiang et al., 2013) or be selected by the lecturer (Ishihama, 2003). At the end, the end result of the projects by the students can either be simple or complex. Some develop simple solutions in the form of household products such as a snap fit container (Kitto, 2000), a tableware sterilizer (Jiang et al., 2014), and a auto-locking door (Nakagawa, 2011). For others, more complex projects are developed such as micro combustion engines (Progrebnaya et al., 2013), a radio amplification device (Lepeshev et al., 2013), and a vibration test rig (Ishihama, 2003).

The second hurdle is to provide motivation to the students. It is not enough to just get a method but also to have a conducive environment where the students have the motivation to pursue innovation. There are two types of motivation which are extrinsic and intrinsic. Motivation that arises from outside an individual as known as extrinsic where mottivation that arises from within an individual is known as intrinsic.

In the standard university setting, students are equipped and tested on specific knowledge. It is hoped that out of their own intrinsic motivation, they will pursue to apply what they learnt to develop an innovation. However, only a mere percentage will take that leap and even fewer will achieve innovation. This TRIZ based subject is structured to provide external motivation to steer the students towards learning and also applying TRIZ to develop novel innovations. Upon achieving it, the students would have more curiosity, courage, confidence, and capability to pursue further innovations. Feedback questionaires are given to the students to gauge their intrinsic motivation of pursuing innovation.

3. Subject Outline

A new subject entitled “MON2801 Leadership & Innovation” was developed using the elements of innovation framework at Monash University. The two month long pilot subject was offered as an elective to first year undergraduate students of all faculties. A total of 91 students from the faculties of engineering, information technology, sciences, and business enrolled. The majority are engineering students where as the others represented 10% of the enrolment.

This subject is structured to be based on TRIZ. Within project teams, the students are required to develop novel and innovative concepts that will help solve an everyday common problem. The projects are carried out in teams. Each of the team has the freedom to choose what project they would like to develop as long as the cost is within thirty American dollars.

The subject is delivered in six main modules. Each module covers a different topic. The various TRIZ tools are picked and aranged in the sequence shown in Table 1 to help the students to complete their new concept development project. The tools covered in this subject are more comprehensive than the ones being delivered in previous research works.

Table 1

Module Outline for the Subject

Module	Topic	Tool & Activity	Purpose
1	Group Formation	Myers Briggs Personality Test	Formation of balanced teams
		Teambuilding activities	Warm up to the actual project work
2	Problem Identification	9 Windows	Find a product to innovate
		Contradiction	Identify problems
		Ideal Final Result	Set the final target
3	Problem Exploration	Function Model	Map the functional relations
		Trimming	Simplify the developed concept
4	Solution Generation	40 Inventive Principles	Develop more possible conceptual solutions
5	Solution Evaluation	S-Curve Analysis	Benchmark the concept
		Patent Search	Technology feasibility
		Supplier Search	Components costing
		Market Search	Commercial feasibility
6	Competition Finals	Oral Presentation	Present to industrial judges
		Poster Exhibition	Present to potential buyers

3.1 Innovator Element

The students have the opportunity to mix with students from various schools. Students are formed in the same groups for the entire semester. Instead of randomly selecting the members of each group, all of the students are required to go through a standardized personality test. The Myers Briggs personality test is used to estimate the personality profile of each student. Through the personality test, their strengths and weaknesses in working in a team are then identified. Each team consists of six or seven student members that have different personalities. This is to achieve a good balance of personalities in all of the teams.

3.2 Motivation Element

This subject grants the students credit points for their undergraduate degree. The internal marks and external marks are split at 70% and 30%. Internal marks are awarded based on the correct application of the TRIZ tools on the project. A weekly report is required of them for every module. This report highlights their usage of the TRIZ tool in their project. For the external marks, there is the final exam. The questions are structured in a way to test the depth of understanding of the theoretical knowledge of the tools.

3.3 Methodology Element

Teaching of the tools are done through lecture and tutorial sessions. The purpose of each tool is stated in Table 1. In lecture, the qualified TRIZ trainer shares the concepts of the tool and also the related case studies. After that, the students were to apply the learnt tools on their project during the tutorial sessions. A written report is is required from them after every tutorial. The correctness of the TRIZ tool application is assessed through these reports.

3.4 Innovation Results

The final innovative ideas developed by the students are conceptual. They would need to justify the technology and commercial feasibility of their concepts. To assess these feasibilities, a competition is held at the end of the semester. In determining the most innovative concept in this project, there are two types of competition that are held at the end of the semester.

Firstly, each team is to present their concept in an oral presentation. Next, the teams are to exhibit the poster of their concepts. People from the industry are invited as judges for the competitions to judge the technological and commercial feasibility of the concepts. The teaching staffs and students in the university are also involved in voting for their most favourite concept.

4. Results & Discussion

4.1 Final Concepts

In this semester, 15 teams of students were formed. From them, there is a total of 15 concepts that are newly developed by the end of the semester. These concepts can be grouped into a few categories.

Two concepts are electronic devices, four concepts are household items, and three concepts are beverage devices. The remaining concepts are related to the smartphone. Three concepts are smartphone accessories and the rest are smartphone applications. Besides being innovative, these concepts are novel too. The novelty is validated through patent database search and market search done on the internet. No other systems that have the similar principles of operation can be identified.

4.2 Gauging the Effectiveness of the Subject

4.2.1 Student Feedback

Towards the end of the semester, a questionaire was sent to all of the enrolled students in this subject. It aims to get feedback about the overall quality and effetiveness of the overall subject structure as well as delivery. Out of a total of 91 students, 26 students responded to the survey. The survey consists of questions in regards to the tools taught, delivery method, and assessment technique. An average score of 4.12 out 5 marks was achieved for each item. The overall high mean scores achieved for this subject represent the satisfaction of the students.

Beyond this subject, the students are interested to pursue to be official TRIZ practitioner. At the end of the semester, a poll was conducted. A total of 28.6% of the students have expressed interest to attend a Level 1 TRIZ practitioner workshop. This TRIZ based subject has shown the potential of extrinsically and intrisically increasing the motivation of the students to pursue innovation even beyond their studies.

In a another open ended survey, the students were asked about their top three favourite aspects of this subject. TRIZ was mentioned the most often in the top three aspects. Teamwork, competition and leadership are the next favourite mentions. This result shows that proposed innovation elements of motivation and methodology are well received by the students. Besides that, the students have also highlighted other diverse favourite aspects of the subject as shown in Figure 3. All of the 91 students contributed their feedback in this survey.

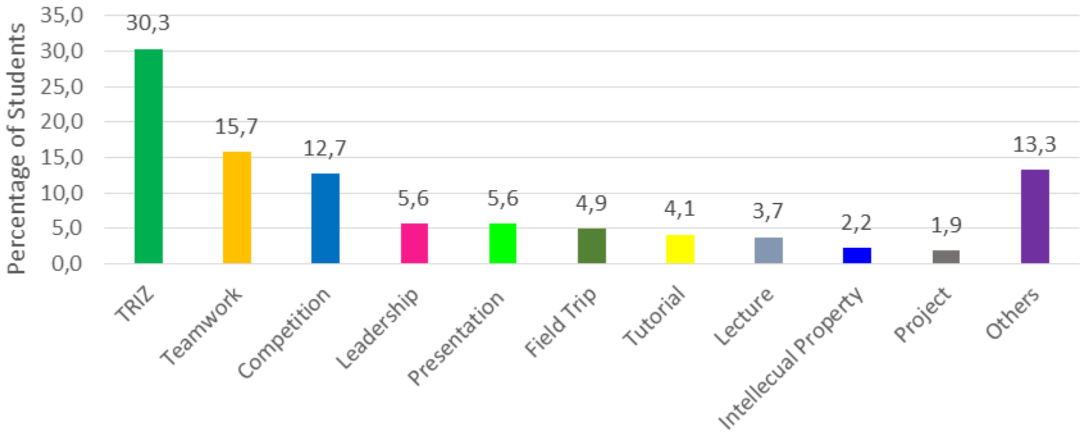

Fig. 3. Favourite Aspects of the Subject

4.2.2 Final Marks

TRIZ has been deemed to be complex and hard to learn by even the practitioners in the industry. Even in their feedback survey, 48.6% of the students have strongly agreed that this TRIZ based subject is intellectually stimulating. Although deemed as a difficult subject, the overall final grades of the students have showed that they have mastered the theoretical understanding as well as the application knowledge of the TRIZ tools. Out of 91 enrolled students, all have passed the subject and have at least a credit grade. More than half of the class obtained a grade of distinction and higher. The grades represent to good understanding and also good application of the innovation skills.

5. Conclusion

Through the research's elements of innovation in education framework, a new subject was developed to teach innovation skills to undergraduate students. They are from technical and non-technical undergraduate degrees. The TRIZ based subject embeds the elements of motivation and methodology to assist the students to learn skills needed to develop innovations. From this pilot group of students, 15 new concepts were developed. These concepts are novel as they are no exact equivalents found in the patent database nor market.

Besides developing innovative concepts, the students have found that the marks reward system and competition setting as motivation to do well. TRIZ is often deemed to be too complex for application. Even though being in their first year in university, the undergraduates in this study have demonstrated their ability to apply the tools effectively in their projects. They have also shown understanding of the theoretical aspect of the tools with the good grades achieved in their final exam.

Moving forward, prototyping and commercialisation will be embedded into the future syllabus of the subject. These additions will validate the innovative claims of the concepts. Industrial partners will be needed for their expertise in carrying these out.

Besides being applicable to universities, this research framework can also be applied to the workplace. Those who are already in the workplace should be equipped with the right motivation and methodology elements to promote the development of higher degrees of innovations.

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THE APPLICATION OF BIONICS COMBINED WITH TRIZ THINKING IN THE INSULATOR DETECTING ROBOT DESIGN

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Abstract

As two widely used methods and theories in the field of innovation design, Bionics and TRIZ have been achieved more significant results in multiple areas. But, they also have their limitations respectively. Firstly, the advantages and disadvantages of Bionics and TRIZ are analysed separately in this paper. Secondly, the creative thinking that combining Bionics and TRIZ is proposed, and a novel design process model is constructed based on Bio-TRIZ theory. Lastly, a new kind of insulator inspection robot was designed based on the design process model verified the effectiveness of the proposed model.

Keywords: Bionics; TRIZ; Combination of Bionics and TRIZ; Insulator Detecting Robot

1. Introduction

Product innovation design means a kind of practice activity which designs novelty, creativeness and applicability products that making full use of human innovation ability and existing science and technology. As two significant innovation methods, Bionics and TRIZ are play an important roles in the field of science research and innovation .

Bionics is a comprehensive interdisciplinary that solving the human needs on the application of theories and mechanisms that discovered from nature and biology. Bionics take natural biological system structure and process of life activity as a basis for the design of technological innovation,imitating and copying,which also opened a new times that demanding from nature transforms into learning from nature [1].

TRIZ is proposed by G.S. Altshuller.The core of TRIZ is the process that solving the invention difficult problems. It is convenient for designers and researchers to solve their problems via the utilization of invention knowledge and experience in different fields[2]. TRIZ is a tool of analysis and solving problems,its research theories mainly include substance-field analysis, ARIZ algorithm, contradiction matrix, effect knowledge base, etc.

Currently, the studies about the combination of bionics and TRIZ are still less in the world, so we put forward a new creative thinking that putting bionics and TRIZ together.Based on the creative thinking, the model of innovation design process is built up. Based on the model, the insulator inspection robot is designed and verified the innovation process in detailed.

2. The combination of Bionics and TRIZ

2.1. The comparison between Bionics and TRIZ

As two widely used methods and theories in the field of innovation design, Bionics and TRIZ have been achieved more significant results in multiple areas. But in comparison, they also have their advantages and disadvantages. We can see them from table 1.

Table 1

The Advantages and Disadvantages of Bionics and TRIZ

Innovation method	Advantages and Disadvantages	
Bionics	Advantages	(1)Utilizing bionics for innovation design has intuitive, concrete and varied characteristics, providing the most intuitive ideas for the designers. (2)The Optimization feature of biological can help designer get the optimization of technology system, structure and function, etc more easily.
	Disadvantages	(1)The Biological systems are consist of multiple coupling factors, the differences between Biological system and engineering system may lead the failure of the bionic design. (2)There are lack theoretical guidance when the Biological Model transfers into bionic design, it is difficult to make an accurate engineering design and which is rely too much on the designer′s experience in the process of conversion.
TRIZ	Advantages	(1)TRIZ theory has a complete innovation design method, from original problem analysis to different contradictions used different solutions, TRIZ theory has complete analysis methods and tools. (2)TRIZ theory has strong probability. For engineering problems and conflicts, it is fully discussion and mature that the elimination of contradiction. (3)The core of TRIZ theory is the evolution theory of the technology system, referring to the implementation of system function which changes the process from low level to high level. The humans can understand this process via TRIZ theory and predict the future development trend of the technology system to achieve the goal of technology innovation.
	Disadvantages	(1)TRIZ theory is highly abstraction and generality, which needed the designer skillfully master the TRIZ theory and the knowledge of the research field. (2)TRIZ theory only provide innovation direction for the designer but didn't provide accurate plan, for specific plan it is still needed to refined with professional knowledge.

By the contrast of table 1, we can see more clearly the advantages and disadvantages between the Bionics and TRIZ theory in the process of innovation design. We can see from this table that there is no theory that can be well complete the innovation design independently.

Due to the above reasons combing the Bionics and TRIZ theory, as a new innovation method is available.Application of TRIZ theory provide theoretical support for the bionics design, using the principle of the biological supplement, deepen and improve the TRIZ theory.By this way, not only can make up for the inadequacy of their theory respectively, but also can clarify designers' innovative ideas and make new design more reasonable.

2.2. Establish Bionics and TRIZ innovation design model

According detailed study of the bionics and TRIZ theory, combining this two theory together with their advantages . After the combination, not only can we use TRIZ advantages in the problem transfer process, but also can use the Bionics knowledge to provide biological phenomenon for the design.

The schematic diagram for bionics combined with TRIZ is shown in Figure.1 The combination between the bionics and TRIZ in the innovation design process mainly reflected as below aspects:

Firstly, in the process of analysis the design goal, we can take advantage of the high generalization and abstraction of TRIZ theory and make the actual engineering problem convert into standard TRIZ problem.Then through TRIZ tools to get the original solutions,and through the original solutions to find the matching biological phenomena,use the bionics research methods to get the final design that comply with the design requirements.

Secondly, when make bionic design, in the process of the biological model transform into the technical model. can make use of the theory of TRIZ tools to solve the conflicts existing in the transformation process, eliminate the contradiction, realize the innovation of product design.Designers also can broaden their design ideas inspired by other biological phenomenon in the process of eliminating contradictory .

Lastly, in the process of innovation design, the application of the bionics and TRIZ theory are repeated and alternation. Based on the analysis of the design requirements, there are also needed many times analysis and solutions of TRIZ theory and many times bionics design to get the final design that satisfied the design requirements.

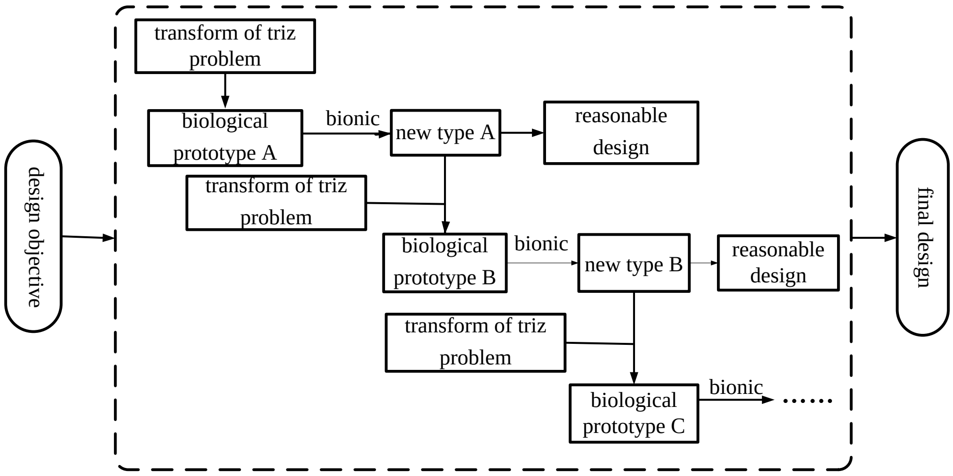


Fig. 1. Schematic diagram for bionics combine with TRIZ

The innovation design that based on the combination of Bionics and TRIZ is means that in the process of innovation design Use of the advantages of both make up for a lack of each other. The model mainly includes four modules as Figure.2 shown below:

Section 1:The requirement analysis.After getting the product performances,functions, appearances and so on via market research methods, designers can achieve their innovation design goals by converting customer requirements into the features of the technical language and make the customer demand for a specific transition.

Section 2: The function analysis. Designers should begin with the total function and refine the sub-function and the unit of total function in order to obtaining the construction of product or system for the design goal which is needed to analysis and solve.

Section 3:TRIZ innovation design.Through the in-depth analysis of the innovation problems,ascertain the conflict aspects not solved and then convert them into the parameters of TRIZ engineering or build the substance-field model. The final design scheme can be obtained by transferring the design problems into standard TRIZ model and taking advantage of the relevant tools of TRIZ theory to solve the innovation problem.

Section 4: Bionics design. Aiming at function analysis and the solution of TRIZ theory, select the biology model for bionics design and then get the design scheme.

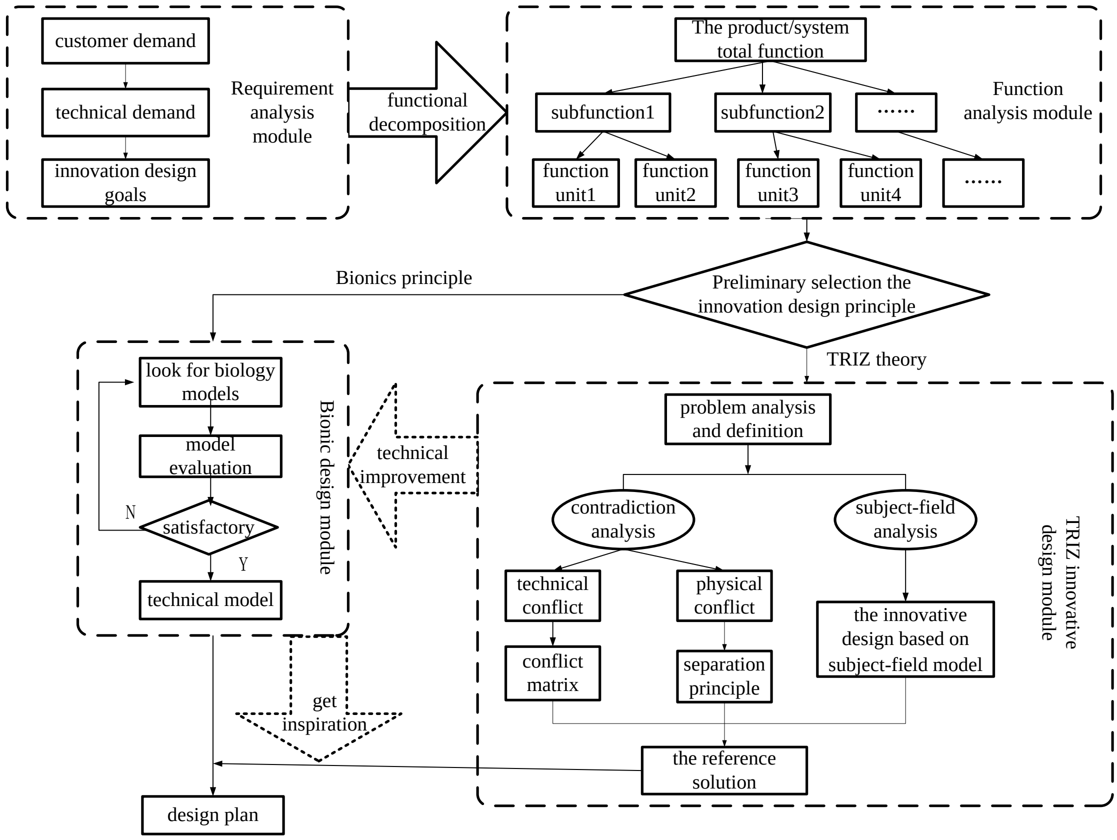


Fig. 2. The innovation design process model based on bionics and TRIZ

In practical application, the specific operations of above model as the following steps:

Step1: Describe and analyze the design problem and analyze the function and structure of the product.

Step 2: Find the biology model from the nature. If we can find the biology model directly, then take its mechanism, organization and function as specific references, converting the biology model into technology model. In this course, the emerging conflict aspects can be solved by TRIZ theory. If it is difficult to find the biology model, then continue make use of TRIZ theory to find standard solution according to the function requirement analysis,find the biology model from the biological database,provide inspiration support for the transformation of the standard solution.

Step3: Evaluate and analyze the design scheme. After repeated tests and verification, eventually get the optimal scheme for the product innovation design.

3. The structure design of the insulator detecting robot

3.1. Problem analysis (step1)

When the motion mechanism of the insulator detecting robot is working, the initial state is implement the function that hold and adhesion the insulator strings. In the process of robot motion, robot needs to overcome the gravity and complete the crawling motion that can be any angle to horizontal direction.Through the analysis of the robot motion, its motion mechanism can be defined as overcoming its gravity and the implementation of crawling motion in different kinds of insulator strings. The main function requirements and relationship definitions are shown as the table 2.

Table 2

The functional requirements and definition of the insulator detecting robot

Function number	Functional requirements	Motion decomposition	The main function definition
1	Holding on insulator strings	The Relatively stationary state between insulator strings and robot	The function of holding tight
2	The relative motion along the insulator string	The Relatively movement state between insulator strings and robot	The function of adhesion and climbing

Based on the design requirements,compared with the original structure,the new structure should have the follow changes ,firstly the robot should have good adaptability and expansibility.Secondly apply buffer device to avoid damage the coating of insulator strings.Thirdly design more reasonable and uncomplicated griping function. Lastly other mobile modes should be applied to improve the climbing velocity in order to improve the work efficiency[4]

3.2. Find biology model and solve the conflict Matrix (step2)

After the effective product analysis, then we looked for biology model from the nature and find that the climbing mechanism of koala is similar to our design goal.In the climbing process of koalas, they use the muscles of the body and limbs holding on the trunk and creep on the trunk using their limbs. In this time, the koala body is griping structure and its limbs are climbing structure adhering on the griping structure. In the view of function analysis, based on the TRIZ theory the biological model of koala provides a design ideas for the insulator detecting robot .

Figure.3 is the structure diagram of imitating koala robot. The upper and lower limbs and body of robot worked together to achieve the function of adhesion by the way of clamping insulator connect with sequins. In the process of crawling, firstly, the upper limbs clip the insulator tightly and the lower limbs sliding to the specified location along the guide bar ,then, the lower limbs fixed , the upper limbs sliding to the specified location ,at this time the robot completed a climbing action.

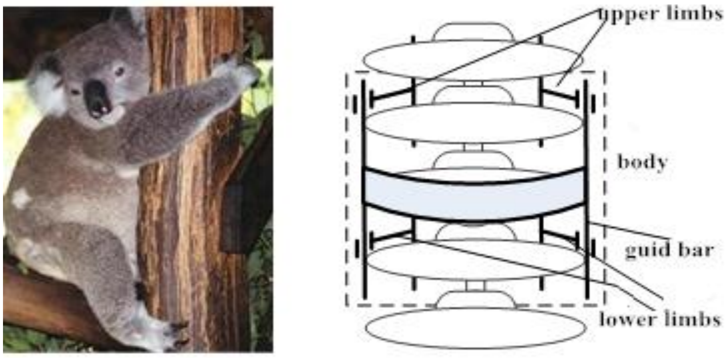


Fig. 3. The structure diagram of imitating koala robot

In the step of problem analysis, considering the 39 general engineering parameters in TRIZ theory[2], the parameters that needed to improve and the deteriorate parameters of the insulator detecting robot can be obtained.

The parameters needed to improve: No.9 velocity, No.25 time loss, No.27 reliability, No.31 harmful object-affected factors, No.33 operability and No.35 adaptability and versatility.

The deterioration parameters include: No.1 weight of moving object, No.32 manufacturability, No.36 device complexity ,No.37 difficulty of detecting and measuring.

Take the chosen engineering parameters into the conflict matrix of TRIZ theory, then get the relevant invention principles as shown in table 3.

Table 3

The innovation design and invention principles of the insulator detecting robot

Worsening Parameters / Improve parameters	1	32	36	37
9	2, 28, 13, 38	35, 13, 8, 1	10, 28, 4, 34	3, 34. 27, 16
25	10, 20, 37, 25	35, 28, 34, 4	6, 29	18, 28, 32, 10
27	3, 8, 10, 40	–	13, 35, 1	27, 40, 28
31	19, 22, 15, 39	–	19, 1, 31	2, 21, 27, 1
33	25, 2, 13, 15	2, 5, 12	32, 26, 12, 17	–
35	1, 6, 15, 8	1, 13, 31	15, 29, 37, 28	1

When different technical parameters are set better according to TRIZ inventive theory, it is inevitable that other technical parameters become worse. In order to optimize the overall performance of the products on-stream, designers should determine such a solution which is a situation that can balance the parameters of improvement and deterioration. On above basis, slect the invention principle that may be used in the design of insulator detecting robot [2,4].

3.3. The overall scheme design (step3)

From the perspective of bionics,after the initial structure design, applied the feasible inventive principles to revise the overall structure of the insulator detecting robot,this is the progess that general solution converted into specification The designer can get the following meaning from the inventive principles:

No.1 The B of Segmentation principle:Divide the objects into easy assembly and disassembly part.In order to make the insulator detecting robot have strong applicability,the modularization design is conducted for the robot griping structure and mobile structure. The corresponding robot modules are adopted and reinstalled for different structures and sizes of the insulator detecting robot.

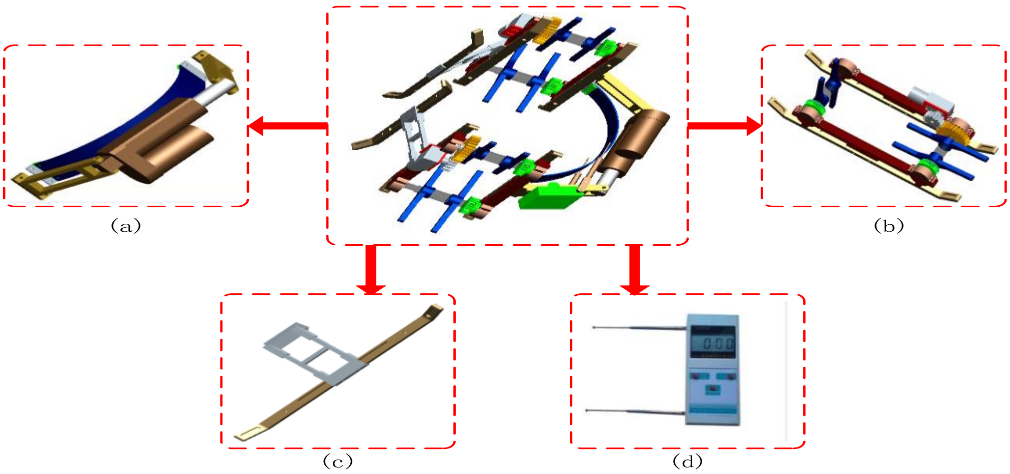
No.8 The A of counterweight principle: The first substance weight is compensated with another substance which can generate the lifting force. The mobile structure is used to provide the robot motive force and overcome the gravity.

No.10 The B of Prior actionprinciple: Make special arrangements for the object in advance, make preparation on time or makes the object in the operating position. Before the robot start to move, the robot griping structure is used to achieve the robot orientation along the axial direction of the insulator strings.

No.15 The B of Dynamic principle: Divide the object into elements with correlations and their relative positions can be changed. Divide the initial grip structure into two location modes the axial and radial directions achieved the functions of the grip and location through their joint actions.

No.20 The C in the part of continuity with effective actions: The reciprocating motion is instead of rotary motion. The wheel claw structure was adopted which can generate rotary motions and makes the robot crept continuously. This way of movement can improve the work efficiency,and achieve the radial location of the griping structure.

According to the above analysis, we can see the modular design of the insulator detecting robot ensures its utility in different working conditions with different modules assembly. As figure.4 shown, the griping structure is consists of the actuating device, moving structure, griping structure and the detecting insulator device. The griping function of the insulator detecting robot is accomplished by the four sections above.



a-Hold driving devices b-Walking devices c-The end of hold device d-Insulator detector

Fig. 4. The whole model figure of insulator detecting robot

The robot design consists of two mainly parts the griping and moving structures. Griping and locating functions are completed by the combined effect of griping and moving structures. According to the annular structure characteristic of the insulator, in order to diminish the robot volume, the griping structure should be or closed to curve as much as possible as Fig. 5 shown below. The step-by-step climbing motion of the initial moving structure is instead of the continuous motion of the claw-crawling structure. The designed structure not only can increase the climbing speed, but also enhance the structure stability and provide the radial positioning function along the insulator strings for the robot griping structure. Fig. 6 is the moving structure diagram.

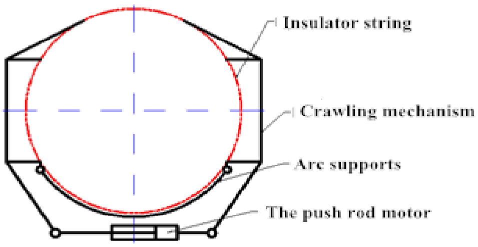


Fig.5 . Hold principle diagram

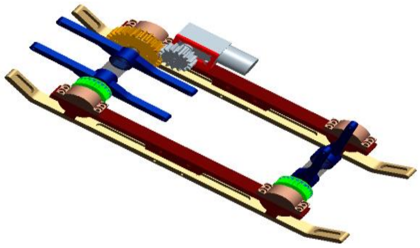


Fig. 6. The moving structure diagram

Figure.7 is the overall structure of the insulator detecting robot. Its moving function is consists of two actions griping and climbing. The griping action depends on the push rod motor. When the push rod motor in the original length, the griping structure opens some degree for disposing the insulator strings as Fig.7 shown. Griping action is accomplished when the push rod motor in the elongation stage.

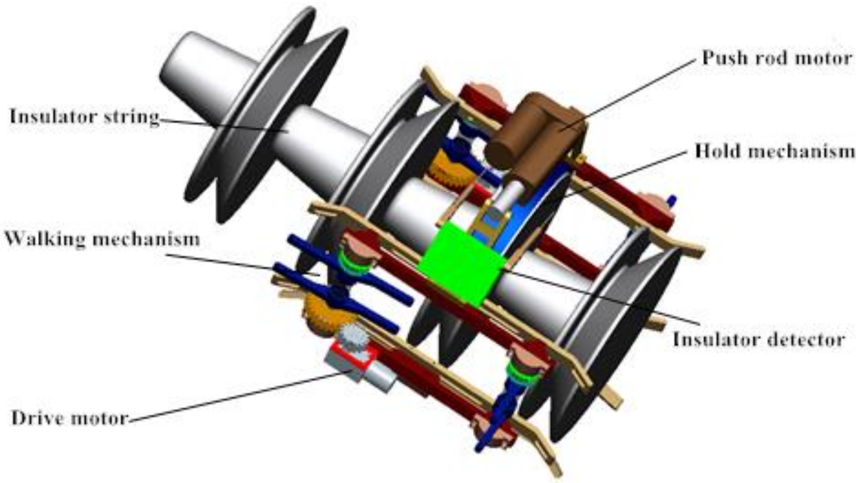


Fig. 7. The structure of insulator detecting robot

To sum up, the use of the combination of bionics and TRIZ innovative design method to design the insulator detecting robot has the advantages of simple structure, stable work, climb better continuity,it also verifies the feasibility and validity of the bionics and TRIZ innovation model.

4. Conclusion

This paper compares the merits and demerits of the bionics and the theory of TRIZ, put forward the standpoint of the combination, analyzed the feasibility of combining the two methods. Summarized in the innovative design thinking mode Bionics and TRIZ theory in the process of innovation design, and the model of the innovation design process is put forward based on the bionics and TRIZ theory. The innovation model can supply more clear ideas for designers and improve the innovation design efficiency.Toward the design of insulator detecting robot, the detailed design methods and procedures are described based on the model and innovative thinking.according to the structure design of insulator detecting robot,verifies the effectiveness and practicability of the B-TRIZ theory in the product design process,which provides a reference value for the product innovation design.

Acknowledgments

This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation.

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THE NEW APPROACH TO PROBLEM-SOLVING ALGORITHM

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Abstract

TRIZ includes a number of tools for problem-solving. However, it can be difficult to select properly a specific TRIZ tool, or a group of tools during a project for a beginner. We need a new approach in using TRIZ tools easily and quickly. Obviously, ARIZ is a systematic approach to solve inventive problem and a sequential process which is developed as an algorithm, but it requires a lot of time to master ARIZ to be used quite freely

This paper proposes a new approach to problem-solving algorithm to be used to select properly a group of tools for some types of problems.

Keywords: TRIZ tools, ARIZ, type of problem, Algorithm, systematic approach

1. Introduction

TRIZ helps to find innovative results more quickly by providing a systematic analysis and inventive problem-solving tools in the technology development process. There are a various of tools for problem-solving such inventive principles, standard solution, scientific effects, function-oriented search, evolution trend, ARIZ etc. in TRIZ.

Recently TRIZ is used also as a tool for solving creative problem in automotive industry. Hyundai Motor Company (HMC) has been getting a successful result in new concept design, quality improvement and cost reduction through about 200 projects since 2008.

However, engineers are trying to use TRIZ for the first time was difficult to determine whether it is appropriate to use any TRIZ tools from the process of utilizing TRIZ for solving problems. Thus, it took a long time to derive ideas for solving problem by using randomly tools learned during the training.

Of course, there is ARIZ that solves difficult and complex problems logically using the various systematic methodology, but it requires a lot of time to master and is not appropriate for beginners to learn TRIZ. Therefore, we developed new algorithm to be used as a guide when they do a project.

In this paper, we propose simplified problem-solving algorithm to be used to select properly a group of tools by type of problem.

2. Analysis of HMC's TRIZ projects

The 67 TRIZ projects were performed at Hyundai Motor Company (HMC) in 2014. As a result of analysis for projects, we found that projects focused on solving the problem of the four types such as new concept design, quality improvement and cost reduction, patent development.

2.1. Classification of Projects

The type of problem covered most frequently in projects is a new concept design, and it accounts for nearly 69% of all projects. Next is the cost reduction by 13% of all projects, and the quality improvement by 9% of all projects. (see Fig. 1)

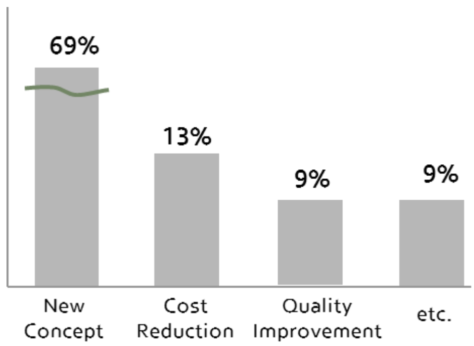


Fig. 1. Classification of TRIZ projects in HMC

2.2. TRIZ tools used in projects

TRIZ tools used frequently in the problem identification stage were function analysis, trimming, root cause analysis, engineering contradiction and su-field model. The function analysis was used most frequently by 28% of all projects. The second was the engineering contradiction and it accounts for 19% of all projects. And su-field model, trimming and root cause analysis were also used often as tools in a problem identification stage.

In the problem-solving stage, the inventive principle, separation principle and standard solution were used frequently. Among them, The inventive principle was used most frequently by 33% of all projects. The second was the standard solution by 27% of all projects. And separation principle and function oriented search were also used often as tools in a problem-solving stage. (see Fig. 2)

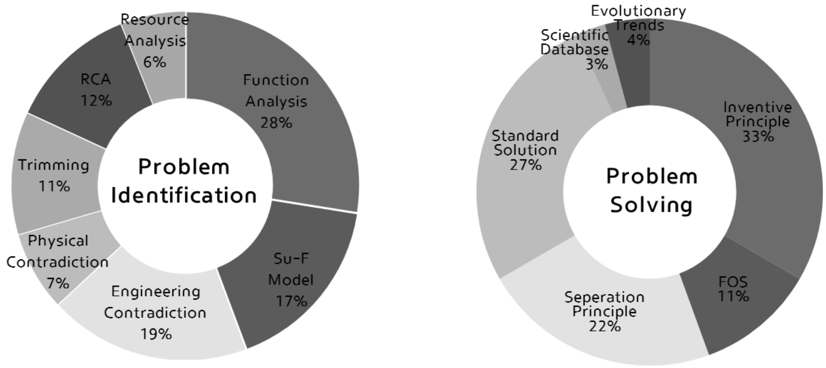


Fig. 2. TRIZ Tools used in projects

3. Description of new Algorithm

We developed the new algorithm that can find quickly and easily innovative ideas base on the analysis of tools used in projects, and provided the roadmap to be used as a guide. This new roadmap is called SPEED TRIZ. (see Fig. 3)

It is classified into four types : cost reduction, quality improvement, patent development and new concept design.

1) Cost Reduction : Function analysis → Cost analysis → Trimming → Resolve contradiction
2) Quality Improvement : Root cause analysis → Key problems → Identify contradiction → Resolve contradiction
3) Patent Development : Current patent analysis → Trimming → Identify contradiction → Resolve contradiction
4) New Concept Design : Function analysis → Su-field analysis → Function orientied search → Resolve contradiction

After resolving contradiction, we need the concretization of ideas and concept assessment and validation.

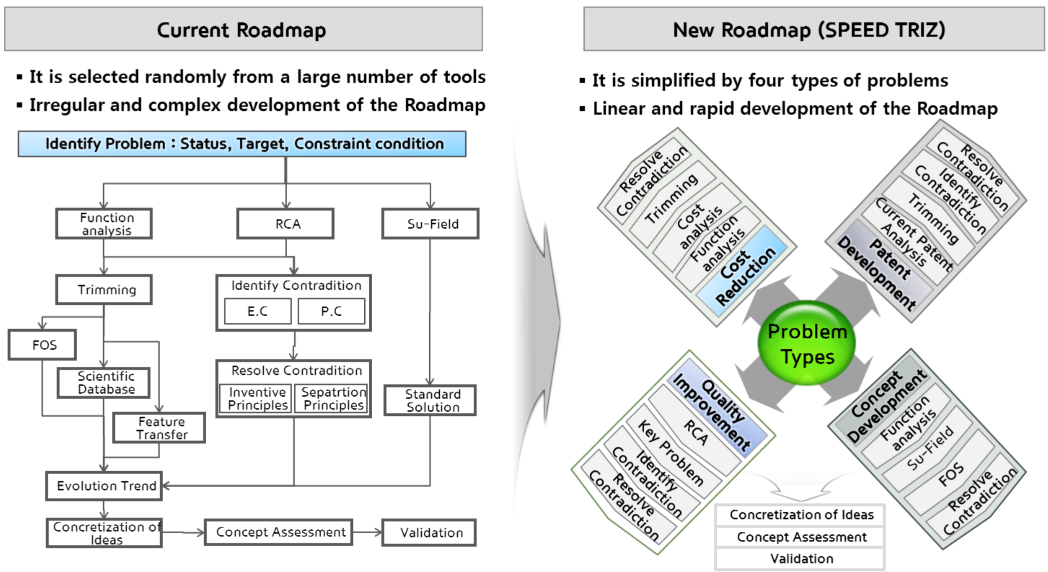


Fig. 3. The comparison of the current roadmap and the new roadmap

Of course, it doesn't necessarily means that you should use this algorithm for each type of problem. For example, although we suggest you solve the problem by using functional analysis, cost analysis, trimming in the case of "Cost Reduction", you can use by adding other tools such as su-field, FOS, scientific database when you want to derive more ideas. And in the case of "Quality Improvement", you can also use function analysis before RCA.

The main purpose of this new roadmap is to help engineers who want to find innovative ideas more quickly and easily.

4. Practical Application of new Algorithm

Among the four types of problems, we are going to explain by giving specific examples for "Cost Reduction" and "Quality Improvement".

4.1. The Roadmap of Cost Reduction

The exhaust system affects the efficiency and the exhaust noise of the engine, and these two characteristics are contradictory to each other. Recently, the muffler of exhaust system requires performance of low noise and low back pressure, and a variable valve is applied to muffler for the effect of the low back pressure.

Therefore, we will try to develop an inexpensive variable valve with the roadmap of "Cost Reduction".

1) Function analysis

First, we need to do the function analysis for a variable valve and muffler. The components of engineering system and super system is identified, and the interactions between components are also identified in the interaction analysis, and then the function modeling is built. The result of the function analysis is shown in Fig. 4.

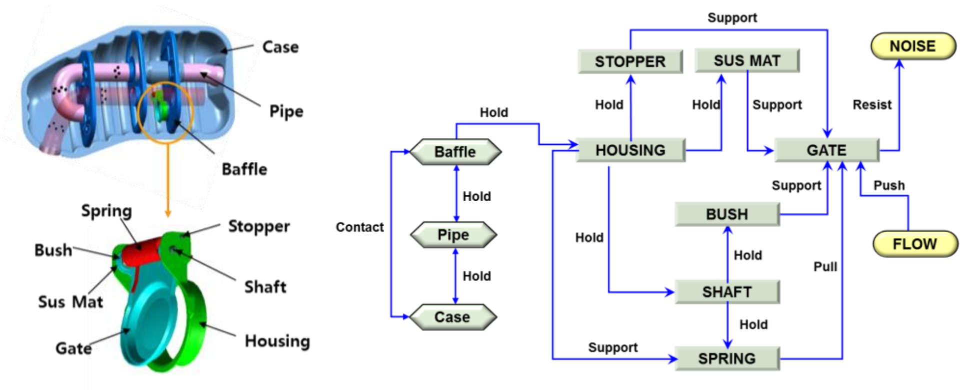
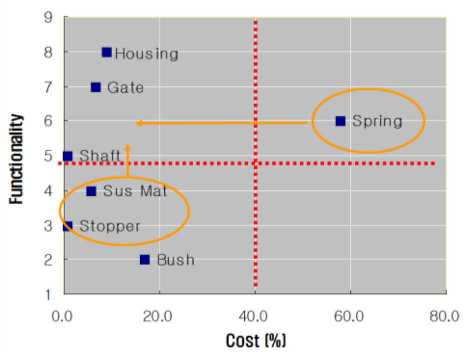


Fig. 4. Function modeling of the current muffler

2) Cost analysis

We analyze the function and the cost for the components of the variable valve, and check the cost and the contribution of function of each component. As the result of the analysis of cost and functionality for components, the cost of spring is higher, and functionality of sus mat, stopper and bush are lower. (see Fig. 5)



Component	Functionality	Cost(%)
Spring	6	57
Bush	2	18
Housing	8	9
Gate	7	7
Sus Mat	4	6
Stopper	3	1
Shaft	5	1

Fig. 5. The cost and functionality of components of the variable valve

3) Trimming

Therefore, we first select the spring that the cost is high as a component to trim, and then select additionally sus mat and stopper that functionality is low.

As the result of trimming, the cost of a variable valve was reduced, but the function of spring to pull the gate was disappeared and the back pressure was increased. Thus, we must find a component to replace the function of pulling the gate using “trimming rule C”, or develop a mechanism of the gate to control itself the opening area of variable valve according to the exhaust gas pressure using “trimming rule B” (see Fig. 6)

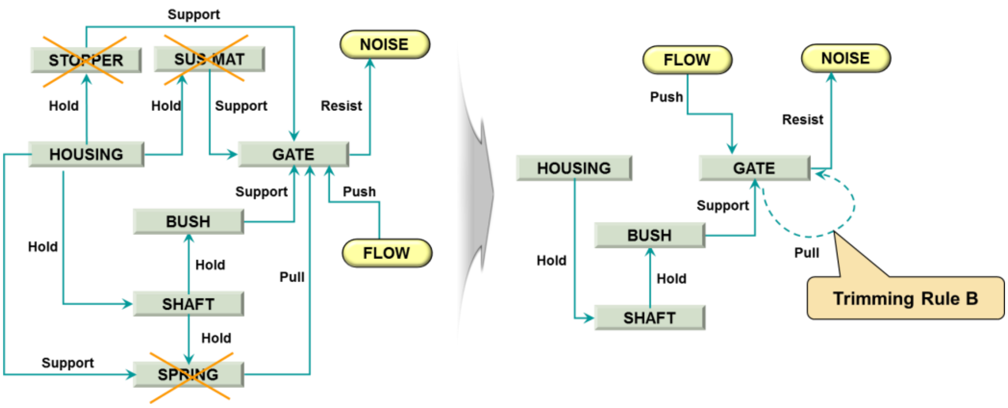


Fig. 6. Function modeling of the variable valve after trimming

4) Identify contradiction

There are two types of contradictions, one is an engineering contradiction and the other is a physical contradiction. An engineering contradiction is a situation, in which an attempt to improve one parameter of the engineering system leads to worsening another parameter.

A Physical Contradiction is two justified opposite requirements placed upon a single physical parameter of an object. These requirements are caused by the conflicting requirements of an Engineering Contradiction.

Therefore, in the case of muffler, the engineering contradiction occurs that the back pressure is reduced if the opening area of a variable valve is increased, but the noise of exhaust gas is increased. The engineering contradiction is formulated as shown in Fig. 7.

	Engineering Contradiction
IF	The opening area of a variable valve is increased
THEN	The back pressure was reduced
BUT	The noise of exhaust gas was increased

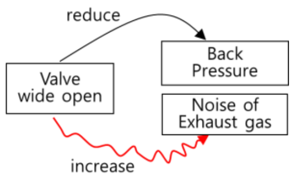
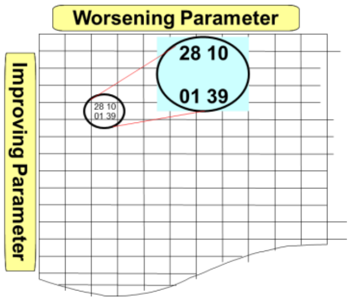


Fig. 7. Formulating engineering contradiction for the variable valve

5) Resolve contradiction

Based on the engineering contradiction, the typical parameters in Altsuller’s Matrix are found out. The inventive principles to help create the new idea which controls the gate itself the opening area of variable valve according to the exhaust gas pressure are recommended.

Among four recommended inventive principles, inventive principle no. 28 is accepted and thereby a new idea is created. (see Fig. 8)



	Typical parameter
Improving parameter	7. Volume of a mobile object
Worsening parameter	13. Stability of composition

recommended inventive principle

No.	Inventive principle
28	Mechanical substitution
10	Preliminary action
01	Segmentation
39	Inert atmosphere

Fig. 8. Engineering contradiction and Altshuller's Matrix for the variable valve

6) Concretization of ideas

Therefore, the new mechanism of the variable valve was designed to be opened the gate itself by the gravitational field according to flow rate and pressure of the exhaust gas.

By adding the weight on the gate, the variable valve does not open in the low-speed range, and opens in the high-speed range. (see Fig. 9)

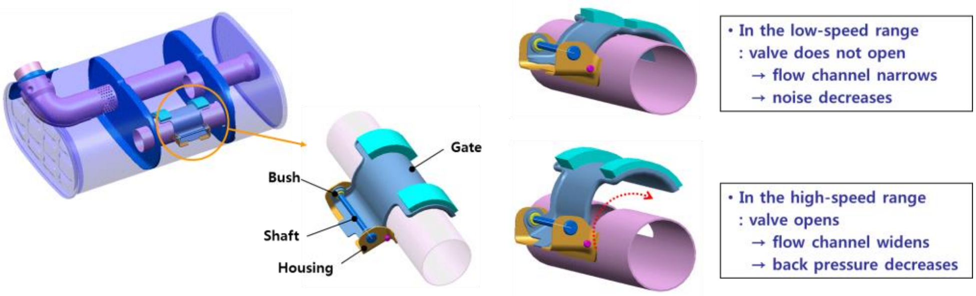


Fig. 9. New idea for the variable valve

As well as the above mentioned a new idea, you can create a number of other ideas using other TRIZ tools, such as separation principle and standard solution, FOS, ARIZ, etc.

Among them, you need to select the several best ideas through the Pugh Matrix, and it must be verified whether new variable valve satisfies the performance of low noise and low back pressure or not, compared to the current structure.

4.2. The Roadmap of Quality improvement

The intake air filter is applied to the intake system to prevent the inflow of dust into the engine. However, if the dust builds up in the intake air filter seriously, the flow resistance is high and the engine performance is not maintained because the dust blocks the air flow.

Therefore, the intake filter is exchanged frequently to maintain engine performance optimally, and it is expensive to maintain.

We will try to develop a new intake filter to reduce the flow resisiance with the roadmap of "Quality improvement".

Fig. 10 shows the composition for the intake filter of the air cleaner. The intake filter of the current air cleaner consists of frame, packing, and media, and the media consists of fine layer, middle layer, and bulky layer.

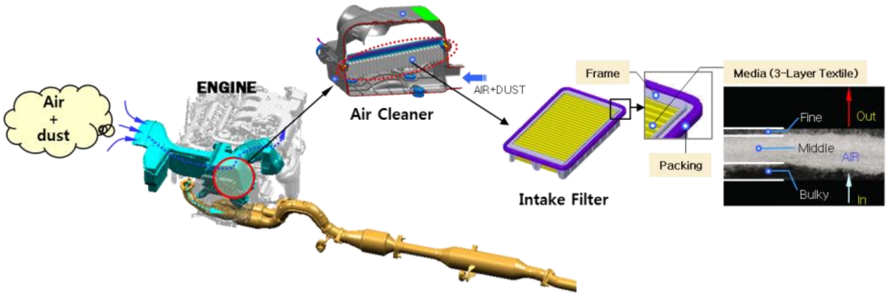


Fig. 10. The composition for the intake filter of the air cleaner

To improve quality of system, we must first find out the root cause causing the problem. The function analysis can be performed in a way to find the root cause, but we suggest to find the root cause using RCA only without the function analysis to solve problem quickly.

1) Root cause analysis (RCA)

Root cause analysis is one of the most important tools for analysis of a problem situation and identification of key problems. Target problems are the problems which must be prevented to perform the main function of system.

A target problem of the current intake filter is that the flow resistance is high, which is caused by the media that does not pass the air sufficiently.

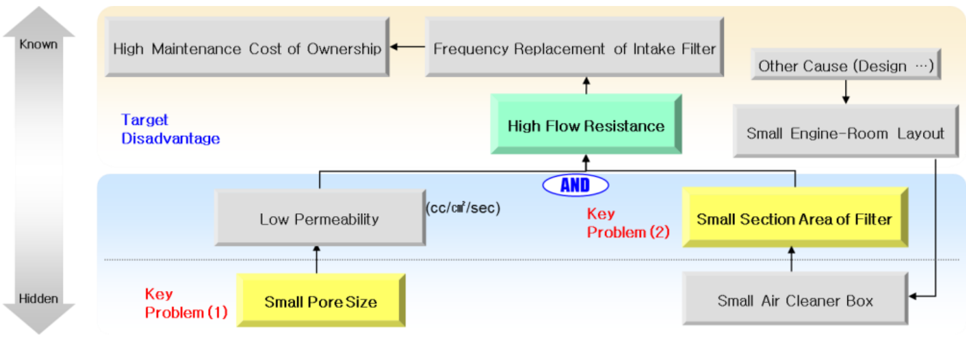


Fig. 11. Root cause analysis for the intake filter of the air cleaner

2) Key problem

As a result of root cause analysis, it is explicit that the key problem of the current intake filter is that the hole size of the media is small, or the section area of the intake filter is small as shown in Fig. 11.

Therefore, the key problems are selected as follows.

1. The hole (pore) size of the media is small
2. The section area of the intake filter is small

3) Identify contradiction

Therefore, in the case of the intake filter, the engineering contradiction occurs that the flow resistance is reduced if the hole size of the intake filter is increased, but the media does not hold the dust sufficiently. The engineering contradiction is formulated as shown in Fig. 8.

	Engineering Contradiction
IF	The hole size of the intake filter is increased
THEN	The flow resistance is reduced
BUT	The media does not hold the dust sufficiently

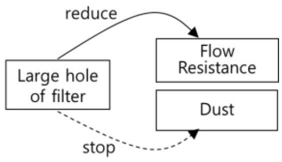
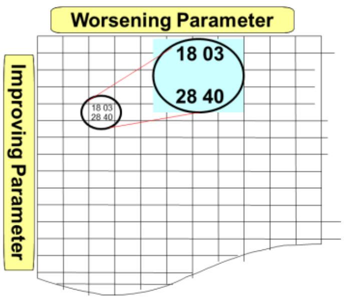


Fig. 12. Formulating engineering contradiction for the intake filter

4) Resolve contradiction

Based on the engineering contradiction, the specific parameters are defined and thereby the typical parameters in Altsuller's Matrix are found out. The inventive principles to help create the new idea which controls the gate itself the opening area of variable valve according to the exhaust gas pressure are recommended.

Among four recommended inventive principles, inventive principle no. 28 is accepted and thereby a new idea is created. (see Fig. 13)



	Typical parameter
Improving parameter	26. Amount of substance
Worsening parameter	27. Reliability

recommended inventive principle

No.	Inventive principle
18	Mechanical vibration
03	Local quality
28	Mechanical substitution
40	Composite materials

Fig. 13. Engineering contradiction and Altshuller's Matrix for the intake filter

5) Concretization of ideas

Therefore, the new media of the intake filter is designed to hold the dust sufficiently by the electrostatic field. The new media holds the dust sufficiently by attaching the electrostatic material on fine layer of the media, even if the hole size of the intake filter is increased.

The hardware for this new idea of the electrostatic field is built and tested as shown in Fig. 10. Test result in Fig. 14 shows that compared to the current media, the new one with electrostatic material added improves the performance in terms of the air permeability, the dust holding capacity, and the filtration efficiency.

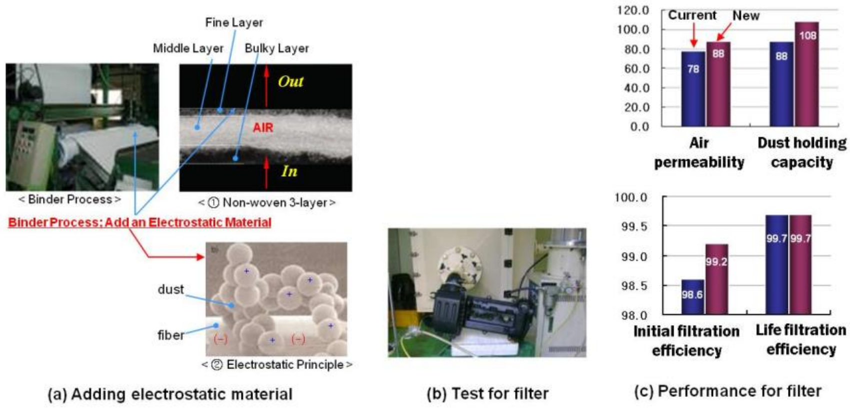


Fig. 14. Test result of the intake filter for this new idea of the electrostatic field

Similarly, the roadmap of "Concept Development" is applied when you need to develop new concepts, and the roadmap of "Patent Development" is applied when you need to develop new patents.

5. Conclusions

As a result of the analysis of tools used in HMC projects, we developed the new algorithm that can find quickly and easily innovative ideas. It will be used as a guide for beginners who are difficult to determine whether it is appropriate to use any TRIZ tools and reduce the time to derive ideas for solving problem. This new roadmap has been used from this year.

We believe that this new algorithm can be useful when you need to reduce the cost and improve the quality and develop the patent and design the new concept not only in the automotive industry, but also in other industries.

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THE WAY TO DEFINE THE GOAL

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Abstract

By using TRIZ, it is possible to solve a real problem after transforming the problem into an inventive problem. A solution would not be desirable, if a goal is not set well. In other words, by designing goal of the project properly, a well-defined problem which leads to desirable solution could be derived. TRIZ is powerful methodology to set an ideal goal with one of its concept ideality. The way to set a goal well and changes of solutions from different goals will be covered in this paper.

Keywords: Ideality, Ideal Final Result, Problem definition.

1. Introduction

1.1. General Requirements

TRIZ was first introduced in Korea 20 years ago as ‘Creative Problem Solving Methodologies’ which could be interpreted in two ways: one is ‘Theory of creative-problem solving’ and the other is ‘Theory of problem solving creatively’. Though, the former is closer to the original meaning of TRIZ which means ‘Theory of Inventive Problems Solving’ [1, 2], the later is more familiar definition of TRIZ to Koreans.

By following original language, Russian, TRIZ is solving theory for ‘creative problems’, not for ‘creative solving’. [3]

Thus, transforming the real problems to creative problems is needed for TRIZ-based problem solving.

TRIZ design the goal of problems first, unlike other idea-thinking methods. [4]

The expression ‘design the goal’ is better than ‘set up the goal’ in terms of TRIZ which recommends describing a goal specifically and clearly. It is important designing the goal in detail to make creative or inventive problems. Problems also should be described specifically including functions required, environment, user and etc.

The goal should be an ideal system. According to TRIZ, ultimate goal is not only to achieve an ideal system but also the required functions.

[Ref.http://freejournal.heliohost.org/freejournal/public/oct2007/the%20concept%20of%20ide

ality%20in%20triz.pdf]

Engineering system is everything around us such as TV, smart phone, washing machine, and each of their components. When each system performs well, a whole system operates properly.

When designing a goal, few steps are considered: analyzing a system, defining functions of system and getting an ideal final result.

It might be impossible to reach a goal based on TRIZ ideality, but the ideal goal guides a direction to a system to reach better state than its initial state in terms of cost and functions.

One general way of designing new practical product is to add some functions; however it could be effective defining a main function of a product first, and then develop function with modifying the goal.

There are 3 kinds of contradictions in TRIZ: administrative, technical and physical contradiction. Generally the project starts from administrative contradiction. The TRIZ process changes from administrative contradiction to physical contradiction by few steps.

1. Check whether the given problem is truly worth to be solved.
2. Analyze the goal by different point of view. When defining problem, the goal should be designed correctly.
3. Analyze the goal by different point of view. When defining problem, the goal should be designed correctly.
4. Is it possible to achieve the goal?
5. How much time is given to reach the goal?
   a. Is it a short-term project or a long-term project?
6. Is the accomplished goal fit in with its surroundings?

The goal should be designed under perspectives above.

2. Systematic Thinking

2.1. Define the goal by multi screen thinking

To design the goal of a project, the multi screen thinking (MST) method is useful. The multi screen thinking, one of the TRIZ tools, helps systematic thinking.

There are few steps in multi screen thinking.

First, analyze super-system based on defined technical system. By segmenting system level, vague initial problem becomes specific problems involving each system levels. Therefore, initial problem should be checked whether it is the problem in technical system level or super system level. In addition, the goal should be designed by correct system level.

Table 1 shows the multi screen diagram. When designing goal 1, you should check whether it could take part as a super system. If possible, relocate goal 1 to super system level. Then, there are two possibilities; whether Goal 2 includes Goal 1 or both same.

The second step is analyzing the past and future of technical system. This is OT(Operating Time) analysis to define when the problem occurs.

The third step is analyzing the goal 3. Goal 1 should be located in higher level than goal 3. For this reason, we have to avoid the situation of goal 1 and goal 3 becoming exactly same. The goal 3 should be the components of technical system (goal 1) in order to be included.

To define the goal 2 and 3, RCA(Root cause analysis) and FA(Function Analysis) are useful.

Last step is analyzing the past and future of super system. If we have to make a new product, the Goal 1 can be transferred to the location of Goal 4 in diagram. We have to make decision whether transference is possible or not, after checking developing period and proper release date. In case of short term project, it's quite common that goal 1 transfers to goal 2 even if the project is about developing new product. However, in case of middle or long term project, the goal 1 transfers to goal 4.

If you want to solve problem using method of TRIZ, define the ideal goal and decide where the goal should be in MST diagram and finally solve the problems in the way of satisfying the goal.

Table 1

Multi Screen Thinking diagram

	past	present	Future
Super system		Goal 2	Goal 4
Technical system		Goal 1	
subsystem		Goal 3	

TRIZ Process might have slight differences between users and problem types. However, general steps of solving problems are similar. Here, the problem is that there is no step for 'define the goal' so far.

The following is the process for solving problems in Gen 3, Samsung, and LG. All of Processes start for 'define problem'. But, there are no significant steps to 'define the goal'.

Problem identification → problem solving → concept substantiation (Gen 3)

Define Problem → Analyze → Generate → Evaluate → Verify (Samsung)

Define problem → Diagnose Problem → Devise Idea → Decide Concept → Drive Concept (LG)

To make inventive problem, goal-decision is important. Depending on goals, problems would be analyzed differently and not easy to solve.

3. Case study

An umbrella development division was told to develop new concept of umbrella. In this case, the task deals with administrative contradiction. The division might search for new techniques to apply or try to add new functions to umbrella. Or, researchers may want to know customers' needs.

From TRIZ's point of view, designing an ideal umbrella is the first task to make a new concept. To define ideal umbrella, the function of umbrella and its target object analysis is required. The function of umbrella is to change the direction of raindrops. An ideal umbrella could be defined as "something changes the direction of raindrops which fall toward someone with no umbrella"

Second, analyze the components and functions of umbrella to know where to begin with. In addition, the analysis is useful to make the umbrella more ideal by modifying some parts of it. Figure 1 shows the components analysis, and Figure 2 shows function diagram of umbrella.

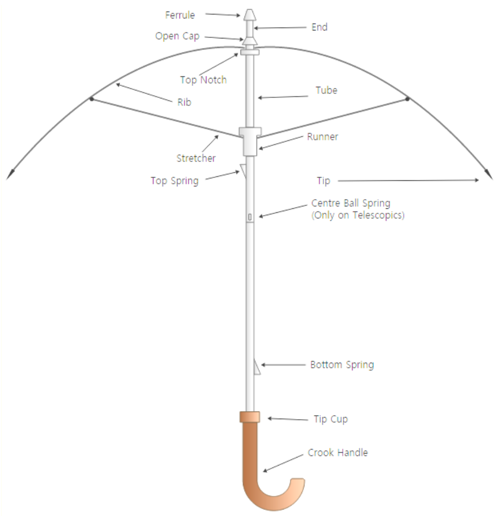

Fig. 1 The components of umbrella

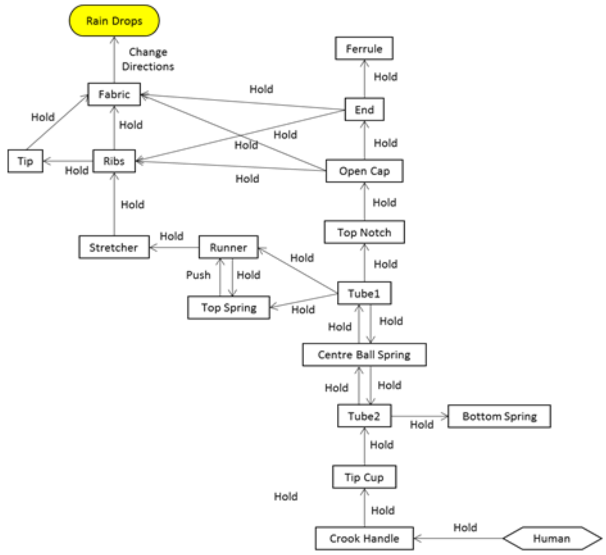

Fig. 2 Function diagram

One uncomfortable thing by using umbrella is that it allows only one hand free. To solve this problem, a goal could be designing umbrella ensuring both hands free. Using a component of super system might be an answer. To hold an umbrella above someone's head with both-hands free, their shoulder and back could be resources. [Figure 3, 4]

Fig. 3

http://gizmodo.com/5337435/shoulderbrella-because-holding-your-umbrella-is-haaaarrrd

Fig 4

http://www.nubrella.com/nubrella.php

Let us consider another problem. The strong wind rarely turns umbrellas inside out. In this case, a goal could be designing an umbrella which does not inside out by strong wind. In other words, an ideal umbrella holds its shape regardless of any forces. [Figure 5] shows an umbrella using fluid mechanics which makes the wind flow past the umbrella. An umbrella in [Figure 6] is made of merged small umbrellas so that there is no possibility to be overturned. Though complexities of both umbrellas make it hard to call them ideal, the initial goal is accomplished.

Fig. 5

www.senzumbrellas.com/collection/home.php

Fig. 6

www.senzumbrellas.com/collection/home.php

If a used umbrella makes indoor wet, goal would be making an umbrella which does not make indoor wet. Figure 7 shows an air umbrella which replace canopy with air curtain. A reverse umbrella in Figure 8 makes the wet part to be folded inside.

Fig. 7

http://www.incrediblethings.com/tech/air-umbrella/

Fig. 8

https://www.pinterest.com/pin/85568461644012020/

When designing an ideal umbrella, Multi Screen Thinking could be a useful tool. Not only table 2 shows that Figure 3 to 8 are examples related to solutions based on modifying subsystem components, but also offer some super system components such as buildings, roads or cloud to be used. If designing an umbrella is a long-term project, it would be not realistic to consider modifying super system components.

Table 2.

Multi Screen Thinking Diagram of Umbrella

	Past	present	Future
Super system		Building, road, cloud, raindrops etc.	Atmosphere, Lifestyle etc
Technical system		Umbrella	
Subsystem		Its component	

If any person could be protected from rain by buildings, roads, underground parking lot and car in any place, there will be no umbrella system. In addition, by using rainmaking system, it is possible to make no rain.

In other words, a goal could be set with different point of views such as installing awning screens throughout whole city, or making rain fall in rain-needed areas only.

4. Conclusions

The results of project are dependent on goals. Let us look at the umbrella again. The result of action to reach a goal changing umbrella itself would be different from that changing a part of umbrella. Furthermore, when considering the function of an umbrella changing the direction of raindrops, a goal could be transit to super system. In other words, by allowing other super system to perform the functions of umbrellas, such as buildings and roads, there is no need for umbrella.

Lots of people try to derive an idea or solve a problem based on the given goal only. However, different ideas or solutions could be derived from the goal designed in other views.

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TRIZ*fest* 2015

TREND OF TRANSITION OF ENGINEERING SYSTEMS TO MICRO LEVEL TODAY AND TOMORROW

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Abstract

The work is focused at almost 40-year history of theoretical content and practical use of the trend "Transition of systems to micro level" from the author of this term within the discipline of TESE G.S.Altshuller (1977 "On trends of engineering systems evolution") till the present day. Examples are shown, which illustrate the use of this trend in practical performance of actual projects, and hypotheses of filling this notion with new meanings are offered.

The essence of the hypothesis, which was set forth, is that the scope of observing this trend should include all phenomena, which are connected with the transition of ES to the zone of IT area, to which the authors applied the term Digital Embodiment of Function.

This format enables to more exhaustively use all new resources of engineering development, which appeared during the last 20 years, which are associated with the development of computer science, Internet and could be helpful in explaining such phenomena as Google, Internet of Things , Defensive computing , Cloud computing and other modern phenomena.

Keywords: substance, field, Digital Embodiment of Function, resources of engineering evolution

1. Prior Art

First time the trend of transition to micro level was described by Altshuller [1]. He wrote: "Evolution of the working members of the system takes place first at the macro- and then at the micro-level. In most of modern engineering systems the working members are "iron parts", for example, screws of the aircraft , wheels of a car, cutters of a turning machine, scoop of the excavator, etc. The evolution of such working members within the scope of a macro-level is possible: "iron parts" remain to be "iron parts", however, they become more perfect. However, the moment inevitably comes, when further development at the macro-level becomes impossible. The system, retaining its function gets fundamentally restructured: its operating member starts to function at the micro-level. Instead of "iron parts" the work is performed by molecules, atoms, ions, electrons, etc."

Altshuller considered the trend of transition to micro level "one of the most important (if not the main) tendencies of development of modern engineering systems." Another appearance of this trend was described as the "trend of increasing su-field quality": "*in su-field systems the* *evolution takes the form of transition from mechanical fields to electromagnetic ones, increase of substance dispersion degree, of the number of bonds between the components and responsiveness of the system*."

Further development of ideas associated with the transition from macrolevel to micro level found their continuation in the works of B.Zlotin, A.Liubomirsky and S.Litvin, V.Petrov and Yu.Salamatov, etc. [2-7]. In their works, transition to micro level was mostly considered in connection with the trend of "increasing dynamicity of engineering systems" that is usually presented by the sequence "monolith – hinge – many hinges – elastic connection – use of gasses and fluids – transition to joints of field nature" [2]. This trend is widely used in the TRIZ-based software, such as TechOptimizer 3.0 and (later) GoldFire 7.1.

In the further works of G.Altshuller, B.Zlotin and others [3,4], the trend of transition to micro level is supported by the well-known diagram MATCHEM suggested by B.Zlotin. However, other authors, e.g. Salamatov [6, 7], did not mention this abbreviation and this mechanism in their publications.

Within the last decades, the knowledge about the mentioned trend has been widely used in multiple practical consulting projects. However, during the last 40 years some absolutely new kinds of engineering appeared, such as nanotechnologies or the Internet and the IT industry in general, supported by the computer science. In our consulting projects of the last years, there are multiple appearance of the above-described trend. Below, we describe our experience in this field and make some generalizations concerning the application of this trend in the nowadays innovations.

2. Practical experience of application of the trend of transition to micro level in consulting projects

2.1. New diagrams for the use in TRIZ consulting

As it is known from the experience of any science, practice always introduces some corrections to theory, models and approaches. The TRIZ theory is not an exception. During the period of 2005 -2015, the authors performed more than 150 consulting projects. The new experience allowed us to suggest new tools that we used in multiple projects. These tools present the considered trend in more details in connection with other (well-known) TRIZ tools.

Practical experience of these projects confirmed that such trends as: "dynamization", "transition to micro-level", "increase of su-Field property" (to use the terminology of G.Altshuller) have much in common and in practice are rather efficiently supported by resource diagrams "MATCHEM" and "resources of aggregate state and structure of substance" – see Fig. 1: (1) the diagram of operations upon kinds of energy, which enabled to collect a unique author's database to be used as a manual, which is augmented from one project to another; (2) Boris zlotin's diagram MATCHEM (6 taxons) in its enlarged interpretation (18 taxons), adapted to projects', associated with semiconductors industry, medicine and food supply industry as well as cosmetic industry; (3) simplified diagram of resources of aggregate states of the substance; (4) the diagram of increasing dynamicity level of the systems [2, 19]; (5) resource diagram of transition to micro level, which makes benchmarking research more valuable and enables to miss a single important alternative system for further operations aimed at integrating them (feature transfer).

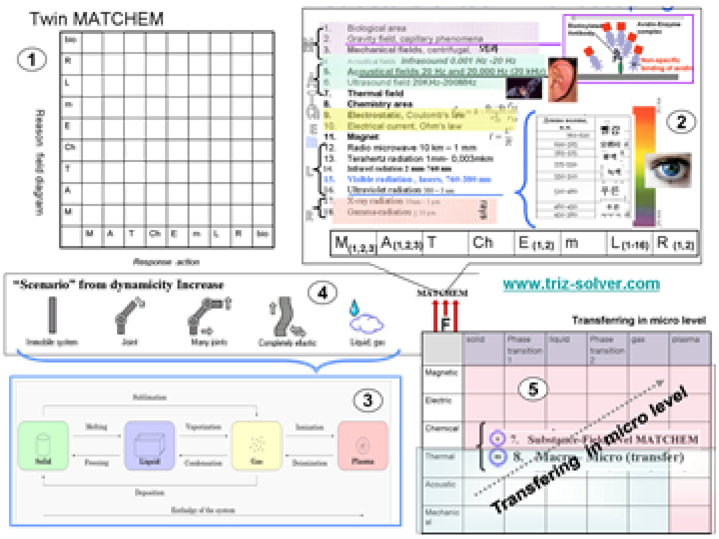

Fig. 1. Five interconnected diagrams used by the authors in the recent projects

2.2. Case studies

Diagram "MATCHEM - MATCHEM"

This diagram was used in the project of 2008 "Systems for utilizing low-potentiality heat" and in the Project of 2013 "Energy supply in business of equipping camping zones". In Fig. 2, we present the use of this diagram to find new technical solutions for the market.

This diagram is an electronic reference book designed for merging the alternative systems according to V.Gerassimov and S.Litvin [18]. Both rows and columns describe the kinds of fields according to MATCHEM (mechanical, acoustical, thermal, chemical, etc.), and cells of the table present possible couples of these fields that can be used in the alternative systems. In particular, combination of light and electricity offers the idea of the combined energy generator that we see in the photograph at the right side of the figure. This idea is now realized in the product "photo-windpower plant WEC -940 FM5" that is available on the market [11]. In this example we can see the appearance of the transition to micro level in a system that previously worked only in the macrolevel.

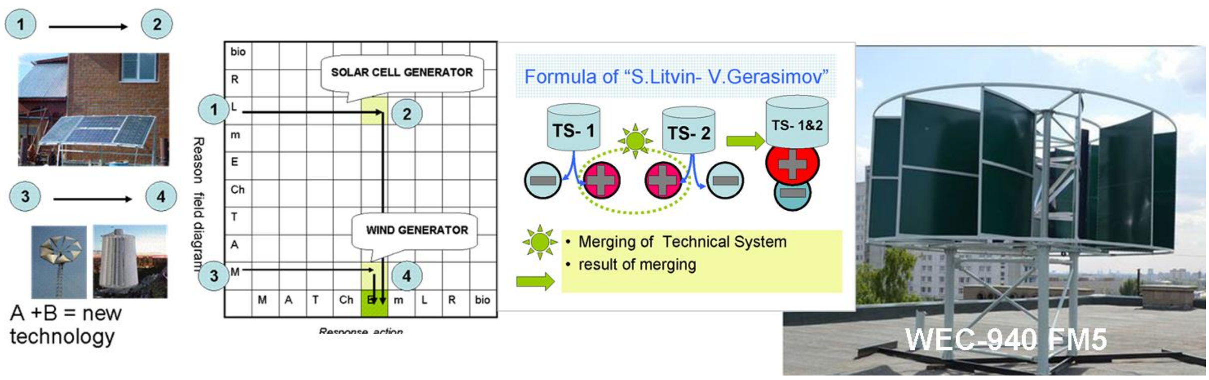

Fig. 2. Search for the alternative systems to merge in energy industry

Resource diagram "Substance – Field"

This diagram (Fig. 3) is another tool for search for alternative systems. This tool appeared helpful at the stage of MPV-analysis [21]. It can also be used jointly with the logics of the process of integrating called MAS (Merging of Alternative Systems) or Feature transfer at the stage of innovative detailed design.

The columns of this diagram, like previous case, describe the kinds of fields according to MATCHEM. The rows describe possible aggregate states of substance: solid, liquid, gas, plasma, and their combinations (solid-liquid, liquid-gas, etc.) Cells of this table, like previous case, suggest the tips about the nature of alternative systems to merge.

In Fig. 3, we present one of the projects performed with the help of this diagram: “Home growing of lettuce”. Lettuces require the temperature of 11 degrees at night and no higher than 18 degrees in the daytime. Cooling system, which is used in Pehlte cabinet, was rather expensive. The diagram enabled to find several appropriate alternative systems (so called “swamp conditioner” and "ice ball") and to successfully reduce the cost of the device.

Later on, the method of integrating alternative systems was used and the results were obtained, which enabled to solve the problems of this consulting project.

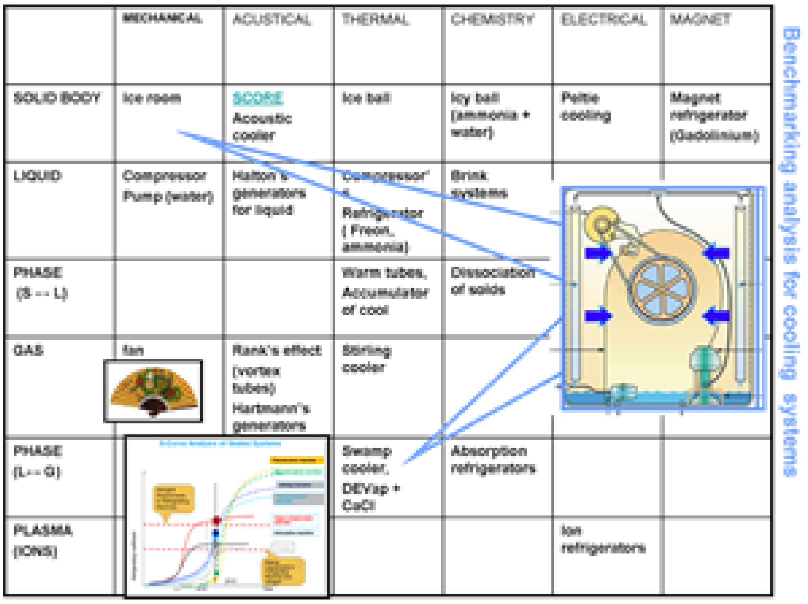

Fig. 3. Application of the Substance – Field diagram in the project “Home growing of lettuce”

3. Digital Embodiment as a New Stage of the Transition to Micro level

3.1. Idea of Digital Embodiment

The works of Yu.Salamatov [6, 7] and other authors contain direct reference to the necessity for “changing substance for a field”. The same logics could be recognized in the diagram of “increasing the level of system dynamization” [2] (Fragment 4 of Fig.2) and in the Standard 5.2.3 (Use a substance as a field) [21].

However, within the last 25 years we observe a great revolution in all kinds of human activity. This revolution is connected with the development of the Information Technologies (IT). In our opinion, this revolution can be considered as the next step of the trend of transition to micro level. Below, we use the term “Digital Embodiment” (DE) for it.

Let us present only few examples of the appearance of this step:

<u>Devices for mathematical calculations</u>: abacus → Nepier's counting sticks → arithmometer → logarithm ruler → calculator on semi-conducting elements → **calculator as a software product in the computer operation system** → **calculator as a cloud service.** What’s next?

<u>Memory of the </u>past: museum → clubs of historical reconstruction → video films on historical themes → ***computer games with historical context*** → ***museum websites.*** What's next?

<u>Teaching and education</u>: car driving instructor → training device for learning car driving → ***computer game "driving car"*** → ***Internet game.*** What's next?

<u>Entertainment</u>: doll → talking doll → electronic toy "Tamagochi" in a smartphone → Internet game "Tamagochi". What's next?

The last links in these chains (highlighted with ***bold italic***) are illustrations of what we consider the Digital Embodiment. We could find many dozen examples in various fields of human activity that demonstrate similar tendencies.

These sequences allow us to formulate a hypothesis that there are some "projections" of the functions of engineering systems in three levels of technologies: ***macro level*** (mechanical, acoustical), ***micro level*** (thermal, chemical), and ***IT level*** as projection of real-life things to the IT area, or Digital Embodiment.

The Digital Embodiment, in turn, can exist in two forms: (1) software in a local computer or a processor-containing device (e.g. smartphone or photo camera), and (2) remote software available through the Internet and cloud services. These forms can differ in the ways and means of their creation and use.

3.2. Case study

In Fig. 4 we see different devices that were developed for smoking and applications connected with smoking.

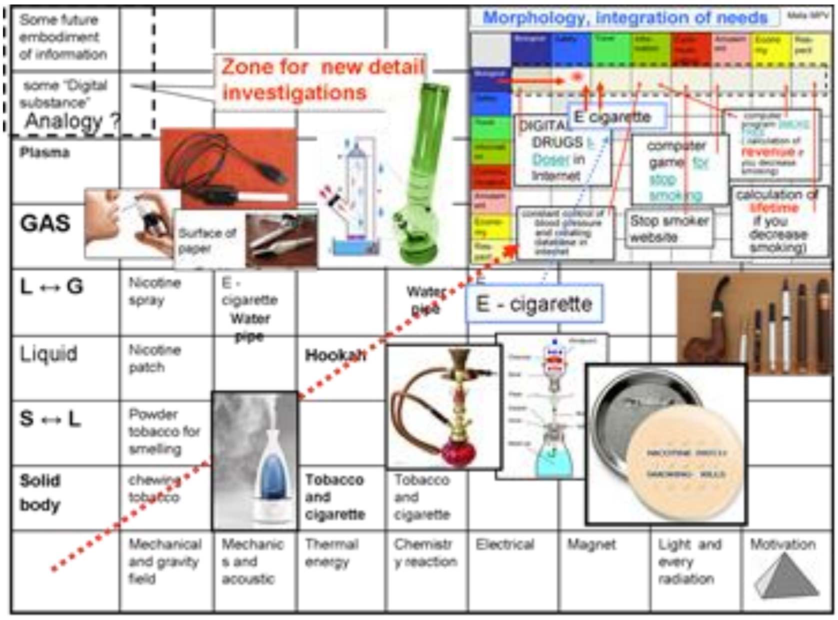

Fig. 4. Development of smoking (and anti-smoking) systems

We can track a chain: chewing tobacco → smelling tobacco → hookah → cigars → water pipe → cigarettes without a filter → cigarettes with paper pipe → cigarettes with a filter → nicotine spray → nicotine sticky tape → ***electronic cigarette***. What's next?

Basing on the above-described general trend, we can continue this line: digital audio drugs "I-doser" [16]→computer program SMOKE FREE (calculation of revenue if you decrease smoking) → computer game for stopping smoking → special websites and group in social network for stopping smoking.

The described diagram allows not only making a high-quality benchmarking research, but also searching for a series of new directions in design, which are preconditioned by the resources of knowledge in the field of physics and chemistry.

4. Discussion

4.1. Digital Embodiment and Real World

In fact, any software project, in the same way as any system of macro-level are aimed at satisfying this or that need of the human.

Let us consider, for example, the variant of “digital cigarettes”. What could that be, if we are targeted at this issue? Obviously, the increase in diameter of vessels of the human marrow, which is triggered by nicotine, could be attained through non-chemical means. In certain research on this topic it is asserted that listening to these acoustic files with a certain rhythm, acts upon the human brain due to so-called binaural rhythms of the brain (Binaural beats) [15], which correspond to the frequencies of the ‘brain waves”, which are generated in listening (with the aid of stereo-earphones) to specially selected sound signals for the left and right ear of the listener. Supposedly so-called digital narcotics (computer programs “I-Doser” [16]) synchronize the brain waves with the sound. As a result of that, they affect psychic state, which is similar in terms of the physiological result to smoking cigarettes.

It seems that from the standpoint of peculiarities of the market features it is not important, if the information on binaural rhythms and physiological effects associated with these rhythms true in a scientific sense, since the well-known “placebo effect” exists.

The same happened in history with 25th frame in the cinema. It was not true in the scientific sense; however, by using this technology, many people could create quite successful products for the market in order to create a more efficient advertising, with the purpose of treating people from vicious habits (addictions) like smoking tobacco or drinking alcohol, or of quick learning foreign languages.

Other components of DE for the function “smoking” are directly connected with (specially created!) websites, which contain useful information for those, who would like to get rid of tobacco addiction (and this is a position “communication” in the diagram 8X8 [13]) or with computer programs, which are intended for the persons, who give up smoking and which calculate daily financial profit from the decrease of the number of smoked cigarettes [14].

With the aid of such an approach it is possible to foresee many future inventions, for example, "smart traffic lights" [17], since this IT technology gives an explicit answer to the question, associated with the cell “safety” in the diagram 8X8.

This approach triggers many other questions asked by researchers, for example:

- What types of systems, if they are classified according to 18 basic functions [10], may yield generation of “smart systems” (smart house, vacuum cleaner, conditioner, telephone, car...), and what types cannot do this?
- What are specific features of the process of projecting the systems to DE depending upon placing them in the diagram of 18 basic functions, where 6 basic verbs are proposed for each type of functions and 3 types of objects of function: substance, field, information (6X3=18) ?

Answering these questions is a subject of future investigations.

4.1. Digital Embodiment and TESE

Existence of the phenomenon of creating the projection of the system to IT area might be associated with the fact that in the process of system evolution any Main Useful Function will be characterized by the phase of regulation, it means that it will develop with the process of measurement, which is already associated with mathematics and programming.

As a rule, any engineering system, in keeping with the trend of "increasing completeness of system parts" has "the robot state" as the final condition, which is impossible without the development of the element "control system", while these are sensors and programs of organizing feedback, i.e., software products from IT area.

In the case of projecting the system to IT area (more general term is DE), the systems retain their main feature – satisfy this or that need of the human or the combination of these needs.

The personal experience of the authors of verification of matrix for integration of needs 8X8 in a large number of actual projects during the last 7 days leaves the hope for a possibility of successful using it also in DE.

5. Conclusions

It is proposed in the present work to augment the trend of "transition to micro level" with one more link and the state of the system called Digital Embodiment of Function.

Several hypotheses are offered for the explanation of this phenomenon and one of the variants of methodological support of analysis: matrix 8X8, which was earlier used as a means for search for new application areas for existing technologies, shall be adapted to the search for tomorrow's goods in the format of Digital Embodiment.

The authors collected the first database of examples, which can in future be augmented by other participants of research and which will enable to discover new directions for research aimed at identifying of all possible mechanisms of the trend "macro - micro – DB", in order to create new tools of analysis and design.

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TRIZ used in iCPA, a Tech Startup

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Abstract

This paper summarizes the process from ideation to implementation of a start-up company called iCPA. It was done by ideating the product using TRIZ Tools, forming a team to work on the product, and iterative improvement using voice of customers and voice of product. There have been three primary models: B to C model (free) – 20,000 users after 3 years, B to B model (revenue-generating) – 2 educational institutions in 2015, and B to G model (entrenchment) – collaboration with the Philippine Regulatory Commission. Once a critical mass is hit, this tool can cause disruptive innovation in education. The goal within 5 years is to have 30 million users.

Keywords: startup, education, platform

1. Introduction

1.1. Worthy Goal

In High Priority Directions for TRIZ Development, the categories of the tasks that fell under the right-most part of the diagram were "How to Find a Right Goal to Be Achieved" and "How to Find a Business Impactful Solution/Technology."

The authors sought to attempt to answer this question by defining "right" and consulting the criteria for selecting a Worthy Goal in G.S. Altshuller's Kak Stat Geniem. High-value companies were also analyzed for commonalities worthy of emulation.

According to G.S. Altshuller, a worthy goal is a solution to a specific unsolved problem. One of the biggest unsolved problems is inequity in quality of life. But after some analysis, it can be said that the most significant cause of inequity in quality of life is inequity of access to quality education, and in the application of that education. Furthermore, people play a huge role in business and more often than not, education has a positive effect, and in particular, business and engineering knowledge.

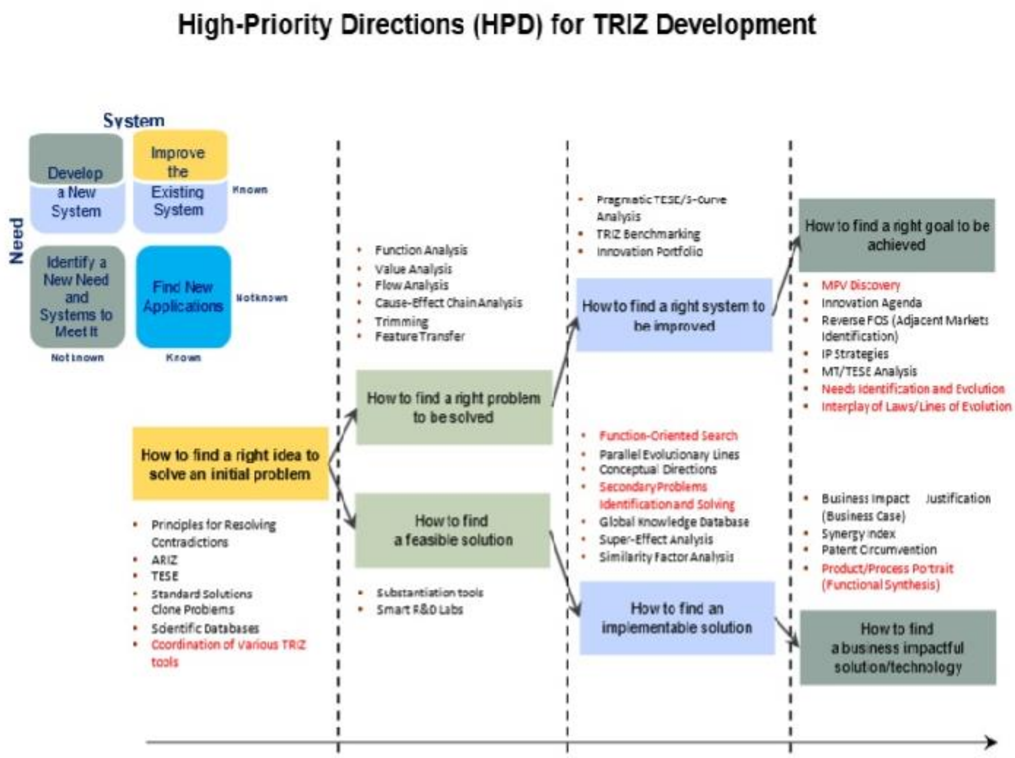

Fig. 1: Framework for the Identification and Selection of High Priority Directions

1.2. Contradictions in the Ideation Process

Ideally, each person educates themselves all their lives. In reality, the generally accepted age range for education is in the range of around 5-24 years of age. As of 2010, 43.2% of Filipinos were in the age range of 5-24. This was a total of about 40 million people, and slightly more today. Contradiction: we wanted to help a lot of people, but not spend an inordinate amount of time in the process of making a positive difference in their lives – in other words, if the number of impacted people suddenly increases, amount of work must not increase as drastically.

TC-1: If a lot of time and effort is spent, then number of people helped improves, but amount of time spent worsens.

TC-2: If a little time and effort is spent, then amount of time spent improves, but number of people helped worsens.

PhC: We must spend time and effort (to help people), and not spend time and effort (so that amount of time spent is reasonable).

Su-Field:

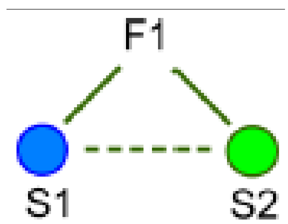

Fig. 2: Su-Field Model. S_1: Authors; S_2: People we desire to help; F_1: Informational field; Interaction: S_1 insufficiently informs S_2.

Resolution (Standard Solution):

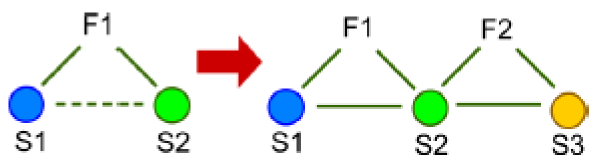

Fig. 3: 2.1.1 Chain su-field; 2.1.2

Solution: Introduce S_2: platform for learning to occur, (F_2 would still be informational)

The conclusion was to work on a single product – a learning platform, and this single product is accessible to multiple users. In hindsight, building an intermediary system was necessary to scale the impact.

Today, access to information is easier than it has ever been, and while this very convenient, this same ease of access can result in a lack of rigor, poor study habits, and declining work ethic among students, ultimately resulting in lack of long-term retention. This is an issue that most educational start-ups are not able to resolve. The second contradiction was related to how the content will be imparted. Access to information can be thought of as the transmission of factual information. The technical contradiction can be stated as follows:

TC-1: If factual information is given, then overall learning time improves, but retention worsens.

TC-2: If factual information is asked, then retention improves, but overall learning time worsens.

PhC: Factual information must be given (to decrease learning time) and asked (to facilitate long-term retention).

Resolution: Principle 4 for Resolving Physical Contradictions – transition from a system to a combination of a system with an anti-system.

Particular Solution: Quizzer (anti- conventional system) with complementary lessons (conventional system) for frequently committed errors.

This particular solution leads to more active learning, as opposed to simply passive learning.

The third contradiction was related to the decision between specialization or generalization of content of this educational platform. The dilemma between specialization and generalization has long been a problem in different fields – education, human resources, investments, etc. – and this case was no different. The efforts must be focused (specialized) yet spread out (generalized). These efforts are translatable into content.

TC-1: If content is specialized, then domain credibility improves, but flexibility worsens.

TC-2: If content is generalized, then flexibility improves, but domain credibility worsens.

PhC: Content must be focused (to improve domain credibility) and generalized (to enable flexible learning).

Resolution: Principle 5 for Resolving Physical Contradictions The system is given property A where a part of the system is given property anti-A.

Particular Solution: Property A: specialized, Property anti-A: generalized. Focusing on general rules - then implementation for accounting, then STEM

Due to in-house accounting expertise, it was decided that accounting be the specialized field. It was decided to attack a particular goal to build credibility: focus first on enabling undergraduate accountancy students pass their professional board exam. The method of imparting content, however, would be done in a generalized manner: concepts-examples-exercises. To refine this process, feedback from users was continually sought out, and design iterations were made. Since the pedagogical techniques for science, technology, engineering, and mathematics (STEM) degree programs are structured in a similar way, this process would allow replication in the technical fields, and eventually the efforts would spread out to high school and below.

2. DEQ-based Review of Related Works

2.1. Information about the System

The system is an education platform. It is a website that consists of content (topics for users to learn, examples, quiz questions) and data-tracking analytics.

The system interacts with students (users), content creators, publishers, formal educational institutions, companies that seek to view analytics as a basis for hiring users, and technology administrators.

The major forces exerted by super-systems that hinder, and conversely, drive the evolution of the system are:

1. quality and quantity of content,
2. quality of the user experience and user interface (UX/UI), and
3. the reputation attached to the learning platform by lead users (brand equity).

The main useful function of the system is to catalyse the learning process of its users primarily using via a quizzer. This will lead to super-effects wherein the formal educational institutions obtain higher educational accreditation, publishers and content creators are given preferred status, and the quality of employees in companies improves, hopefully subsequently improving company productivity.

The factors for expense to provide these useful functions include accumulating content and content quality checks, UX/UI improvements, and communicating within the team and with other companies (publishers, hiring companies, multinationals, etc.). For the moment, none of these functions can be automated.

2.2. Information about Similar Systems and Competitors

Other systems that perform similar functions in the same area are Coursera, EdX, Brilliant, MIT Open Courseware, Edmodo, Google Classroom, Moodle, Udacity, Khan Academy, Blackboard Inc, Quizlet, and on the local front, PassExams.ph.

There are three main drawbacks that are hindering their success. First, there is a certain type of rigor that is undergone in traditional school that open education students have the option to bypass. This leads to a lack of focus, and therefore, a less likely chance that a student completes the program, as evidenced by the low average completion rate for online courses. Second, the other systems are more focused on presentation of information rather than testing the application of that information, which iCPA is fundamentally based on. Third, they are confronting the traditional education head on rather than complementing it. It is a them-*or*-us rather than a them-*and*-us.

3. Methodology

3.1 Product

In 2012, the authors endeavoured see if they could to pursue the worthy goal of reducing inequity by attempting to partially solve some education problems. The decision was to expand upon a pet project called Kap Quizmaster, a blog and email subscription containing accountancy questions to help students prepare for the Certified Professional Accountant (CPA) board exam. This blog had 200 followers. Resolving the contradiction of we must spend time and effort but not spend time and effort, the idea for an educational platform iCPA was formed. In 3 years, it has grown to over 20,000 users by utilizing social media, user analytics, feedback, and frequent design iterations (without straying from the main useful functions).

3.2 Market

As of 2010, 43.2% of Filipinos were in the 5-24 age range. This is a total of about 40 million people. To sustainably and organically expand, the team focused its efforts on creating a frictionless learning platform while using content for accountancy, with the end in view of replicating it in other fields – engineering, business, finance, and kinder to Grade 12 (K-12) education.

In 2014, Filipino-Saudi Arabian accountancy review center PMECPAR commissioned iCPA to produce a platform specifically designed for their students and their teachers. Later that year, LinkedIn approached iCPA expressing interest in the level of user engagement on the learning platform and on social media sites Facebook and Twitter. IBM also came up to iCPA to express interest in hiring users who had just graduated – with iCPA functioning as a human resources intermediary.

Due to the quality of questions and the learning platform's interface, the Professional Regulation Commission contracted iCPA to develop an online testing platform for vocational courses. Adamson University recently partnered with iCPA to create a private learning portal hosted by iCPA with content related to STEM fields.

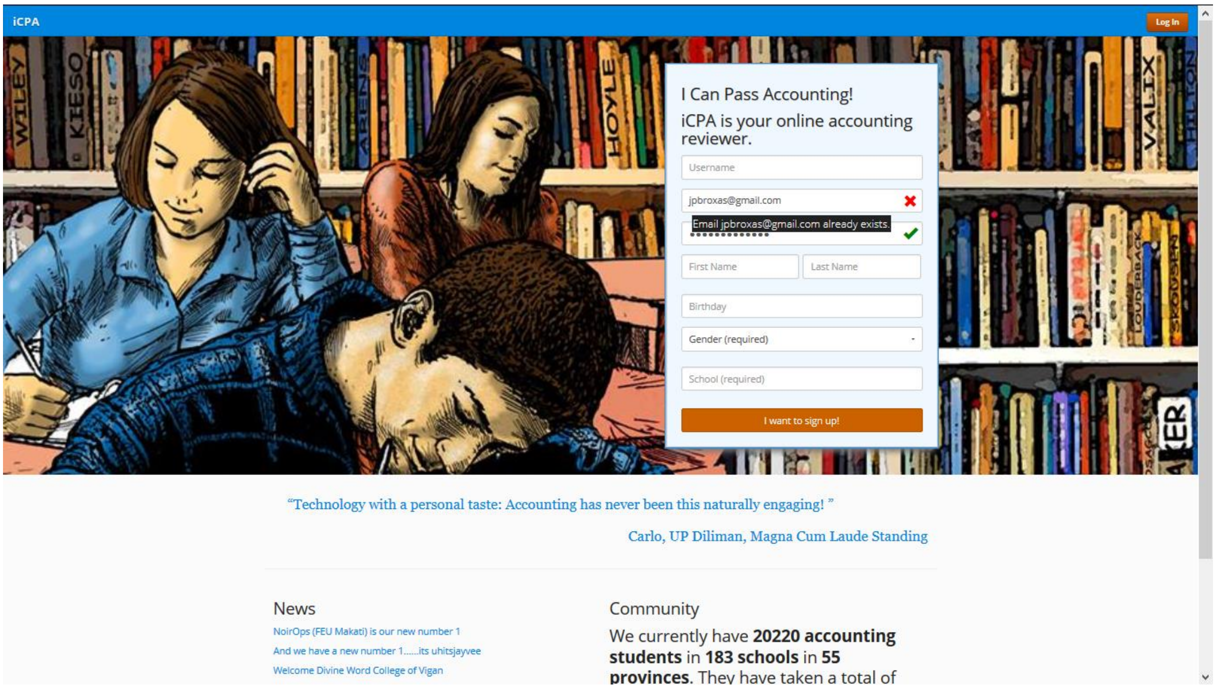

Fig. 4: Screenshot of Landing Page

3.3 Company

Originally, this endeavour functioned only as a hobby to test our ideas and instant gratification when users would increase. The focus was initially accountancy due to in-house domain expertise. CPA popularly stands for Certified Public Accountant, but iCPA stands for I Can Pass Accounting. When PMECPAR commissioned a private platform, we realized this might be a profitable activity. The company is still a start-up focusing on brand equity for sustainable growth. When STEM content was added, it was changed to I Can Pass Anything. In the future, if iCPA is able to expand beyond education, the acronym can stand for I Can Pursue Anything. The members of the company have the following tasks: content creation, collation and maintenance, platform administration, forming strategic partnerships with interested companies, and social media marketing.

4. Results

The business to consumer model, which is free, garnered 20,000 users after 3 years. For thte business-to-business model, as of 2015, iCPA has partnered with 2 educational institutions. Functionality was added to enable education administrators (lecturers, professors, deans, etc.) to view quiz item accuracy and gain better data about students. The business to government model, whose goal is to increases the company's brand equity, is so far collaboration with the Philippine Regulatory Commission. It is hoped that in the future, collaboration with the Department of Education and the Commission on Higher Education will occur.

5. Conclusions

Using the S-Curve analysis with the guidelines found in Designing Business Projects (Petrov, 2006) and Directed Evolution (Zlotin and Zusman, 2001), it can be concluded that the product-company-market is in combination: P1C1M2.

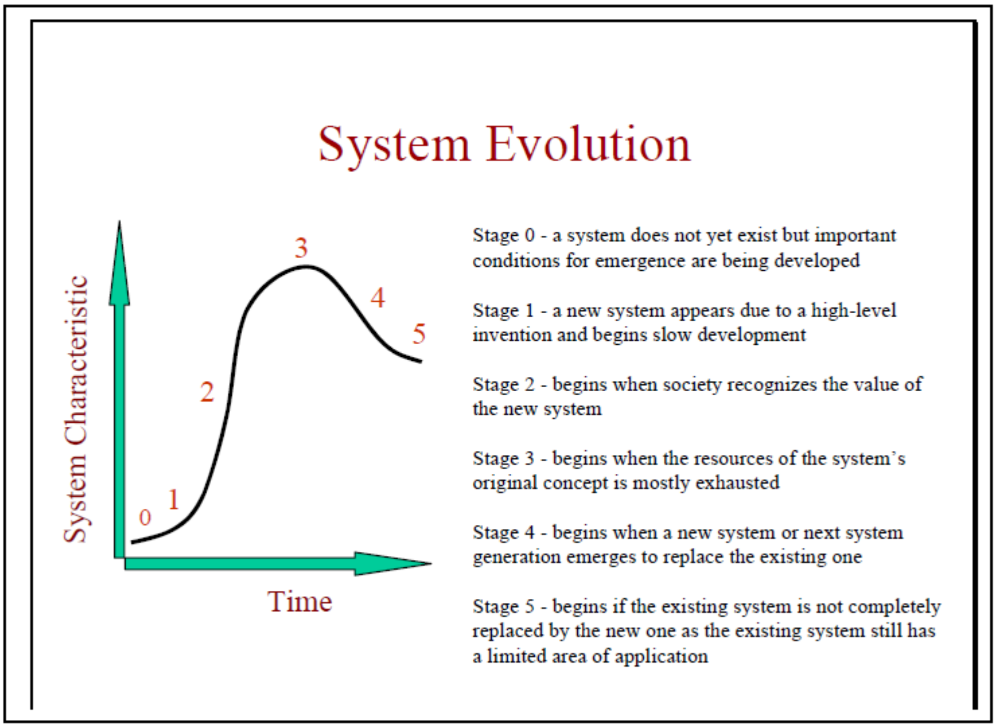

Fig. 5: S-Curve (Zlotin and Zusman, 2001)

Possible opportunities for innovations in the future: for education – automatically converting information into quiz questions and catalysing conversion of knowledge into skills, for business – catalysing the shift from tangible assets to non-tangible assets, such as human skills and intelligence, and for the content generation model – crowdsource, possibly entirely bypassing the publishers.

Acknowledgements

The authors would like to thank TRIZ Masters Valeri Souchkov, Mijeong Song, Vladimir Petrov, Nikolay Shpakovsky, Boris Zlotin and Alla Zusman, TRIZ Practitioners Teong San Yeoh, Eng Hoo Tan, Horst Naehler, Isaac Lim and Zulhasni Abdul Rahim, and computer programmers Victor Javier and Philip Nery for their encouragement, inspiration, feedback and/or support.

The authors would also like to acknowledge the importance of the late G.S. Altshuller and the late Nikolai Khomenko, whose TRIZ works available on public domain spurred Patrick's initial interest and zeal for TRIZ.

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TRIZ SYSTEMATIC INNOVATION FRAMEWORK AND PROGRAM TO SUPPORT A GOVERNMENT LINK COMPANY'S INNOVATION POLICY

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Abstract

Innovation is an important agenda in Malaysia. The National Innovation Strategy and National Innovation Model set the direction and serves as guidelines with regards to innovation for individuals and organizations in Malaysia. Tenaga Nasional Berhad (TNB) is a government link company and has initiated an innovation policy to inculcate an innovation culture among its employees. This paper presents a TRIZ systematic innovation framework and program proposal that was submitted to TNB in a recent open innovation competition that was organized by the company to tap innovative ideas for it to consider in implementing its innovation policy. The proposal has been accepted by TNB as one of the top 20 innovation proposals from over 260 proposals that were submitted by employees in the TNB group of companies. The author has started a bottom-up approach based on the proposal to promote TRIZ to UNITEN students and employees in a number of TNB departments. Experience to-date has indicated that a top-down approach as in the proposal is necessary for an effective adoption of TRIZ by TNB employees.

Keywords: TNB, innovation policy, TRIZ, framework, program.

1. Introduction

Tenaga Nasional Berhad (TNB) is a government link company (GLC) which is also a public listed company with Bursa Malaysia (formerly known as Kuala Lumpur Stock Exchange). GLC companies in Malaysia is defined as companies which the government has a controlling stake [1] through the federal government-linked investment companies [2]. GLCs represent 36 percent of the market capitalization of the stock market in Malaysia and therefore they have a very significant role in the development of Malaysia's economy [3].

TNB's core business is in the generation, transmission and distribution of electricity in the peninsular of Malaysia [4]. TNB has many subsidiary companies and one of them is Universiti Tenaga Nasional (UNITEN) which is a wholly owned private institution of higher learning. TNB has a foundation, Yayasan Tenaga Nasional (YTN) that provides financial assistance to students including to those studying at UNITEN. Many of these YTN sponsored students will eventually work for TNB if they satisfy the academic requirements and passed the job interviews.

The government of Malaysia views innovation as an important agenda in the country and therefore has a National Innovation Strategy [5] and a National Innovation Model [6] to guide individuals and organizations to become more innovative. Examples of action plans in the innovation strategy include the requirements that graduates must know about an innovation methodology while the workforce must master an innovation methodology [5].

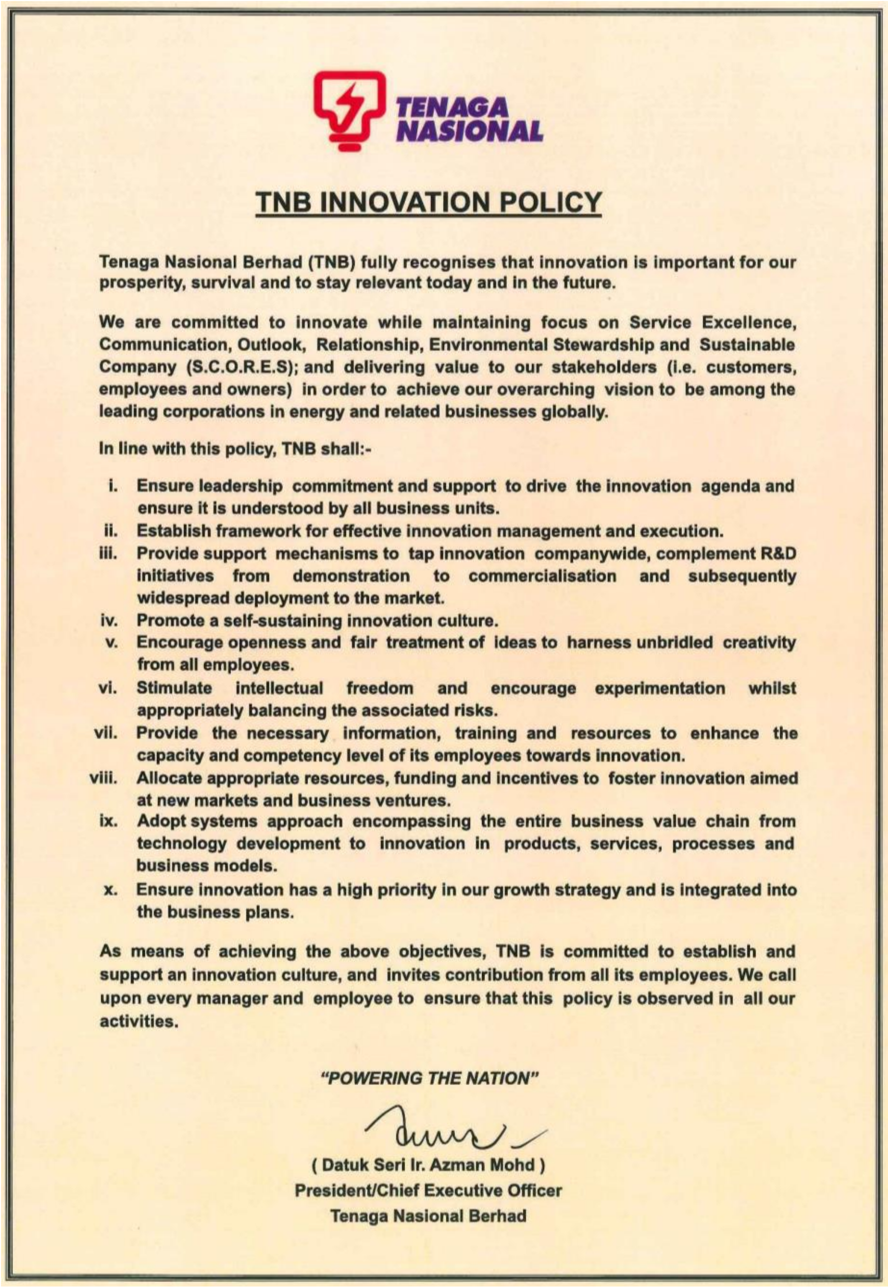
TNB has taken an innovation initiative by having an innovation policy recognizing its importance to its survival and prosperity (refer to Figure 1). Among its innovation policy statements are to,

1) "Establish framework for effective innovation management and execution",
2) "Promote a self-sustaining innovation culture", and
3) "Provide the necessary information, training and resources to enhance the capacity and competency level of its employees towards innovation" [4].

However it should be noted that achieving an innovation culture in a company can be challenging. A study by Accenture of executives in over 500 companies in the US, France and the UK in the year 2013 revealed that only 18 percent believe their company's innovation delivers a competitive advantage [7].

TNB had launched the TNB Open Innovation Contest 2014 on 20th October 2014 for the period ending 31st January 2015 to get all employees to participate in innovation initiatives and to tap innovative ideas from them. One of the themes for the submission of innovation proposals is to inculcate an innovation culture in TNB. Proposals for this theme need to achieve at least one of the following requirements: 1) improve TNB innovation culture, 2) increase TNB's intellectual property, 3) gain recognition as among the most innovative company in Malaysia, regionally and globally, and 4) achieve a sustainable innovation culture.

The author took advantage of this opportunity by proposing a TRIZ systematic innovation framework and program to support the TNB innovation policy under the inculcating an innovation culture in TNB theme. In preparing the proposal, the author acknowledged that there are different kinds of acceptance of TRIZ in companies – some people use it, others view it as an interesting tool but do not use it, and to some people, they have developed a kind of allergy to TRIZ [8]. Hence, it can be a challenge to introduce, teach and use TRIZ particularly for developing an innovation culture in an organization.



TENAGA NASIONAL

TNB INNOVATION POLICY

Tenaga Nasional Berhad (TNB) fully recognises that innovation is important for our prosperity, survival and to stay relevant today and in the future.

We are committed to innovate while maintaining focus on Service Excellence, Communication, Outlook, Relationship, Environmental Stewardship and Sustainable Company (S.C.O.R.E.S); and delivering value to our stakeholders (i.e. customers, employees and owners) in order to achieve our overarching vision to be among the leading corporations in energy and related businesses globally.

In line with this policy, TNB shall:-

i. Ensure leadership commitment and support to drive the innovation agenda and ensure it is understood by all business units.
ii. Establish framework for effective innovation management and execution.
iii. Provide support mechanisms to tap innovation companywide, complement R&D initiatives from demonstration to commercialisation and subsequently widespread deployment to the market.
iv. Promote a self-sustaining innovation culture.
v. Encourage openness and fair treatment of ideas to harness unbridled creativity from all employees.
vi. Stimulate intellectual freedom and encourage experimentation whilst appropriately balancing the associated risks.
vii. Provide the necessary information, training and resources to enhance the capacity and competency level of its employees towards innovation.
viii. Allocate appropriate resources, funding and incentives to foster innovation aimed at new markets and business ventures.
ix. Adopt systems approach encompassing the entire business value chain from technology development to innovation in products, services, processes and business models.
x. Ensure innovation has a high priority in our growth strategy and is integrated into the business plans.

As means of achieving the above objectives, TNB is committed to establish and support an innovation culture, and invites contribution from all its employees. We call upon every manager and employee to ensure that this policy is observed in all our activities.

"POWERING THE NATION"

(Datuk Seri Ir. Azman Mohd)
President/Chief Executive Officer
Tenaga Nasional Berhad

Fig. 1. TNB Innovation Policy [4]

2. TRIZ systematic innovation framework and program

The proposed TRIZ systematic innovation framework to support the TNB innovation policy is illustrated in Figure 2. The framework is to be viewed in conjunction with the proposed TRIZ program to inculcate a sustainable innovation culture in TNB in Figure 3.

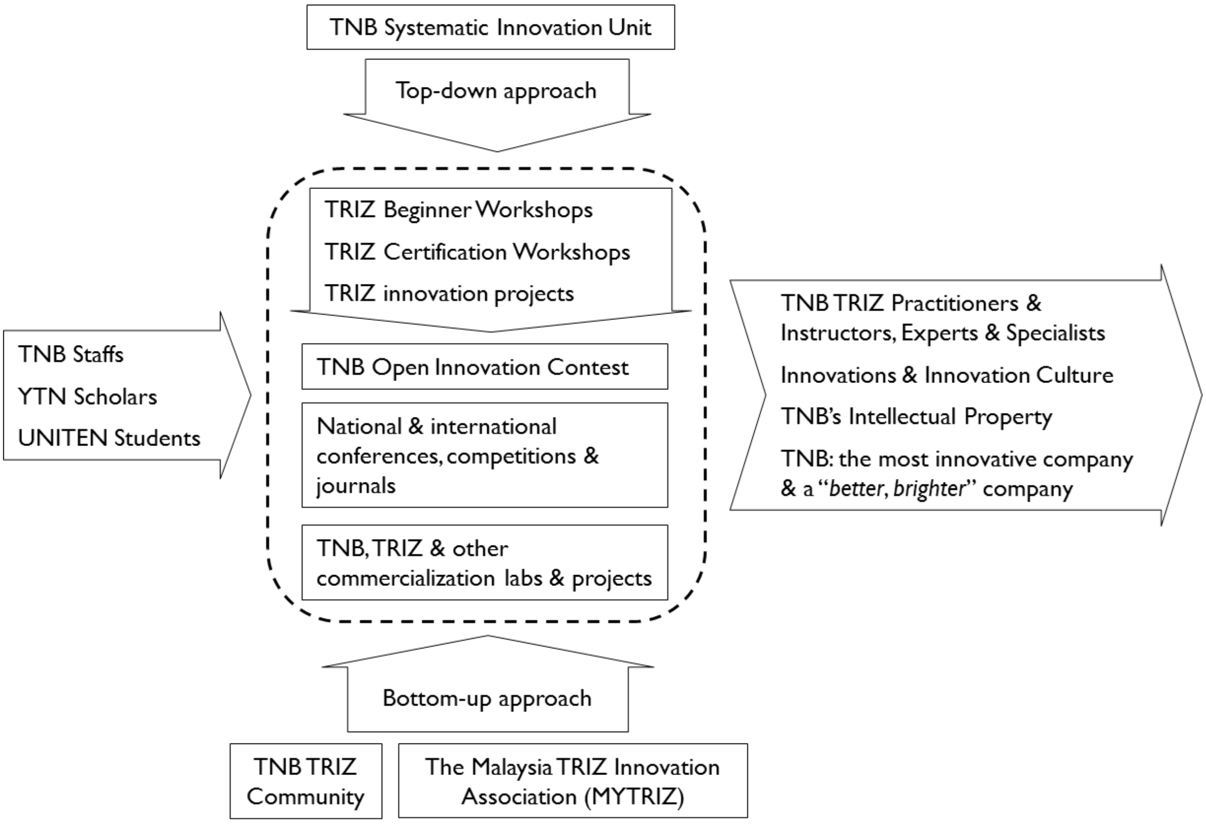


Fig. 2. The proposed TRIZ systematic innovation framework to support TNB innovation policy

The staffs of TNB, YTN scholars and UNITEN students would take the TRIZ beginner workshop and TRIZ certification workshop. TRIZ beginner workshop is a non-certification workshop to learn a smaller number of tools and then use it one at a time. This approach is necessary for TRIZ to be learned and used by as many people as possible and for them to start inculcating an innovation culture. YTN scholars and UNITEN students can take advantage of the TRIZ Practitioner certification when applying for jobs with TNB as well as with other companies particularly those that has already adopted TRIZ such as Samsung and General Electric.

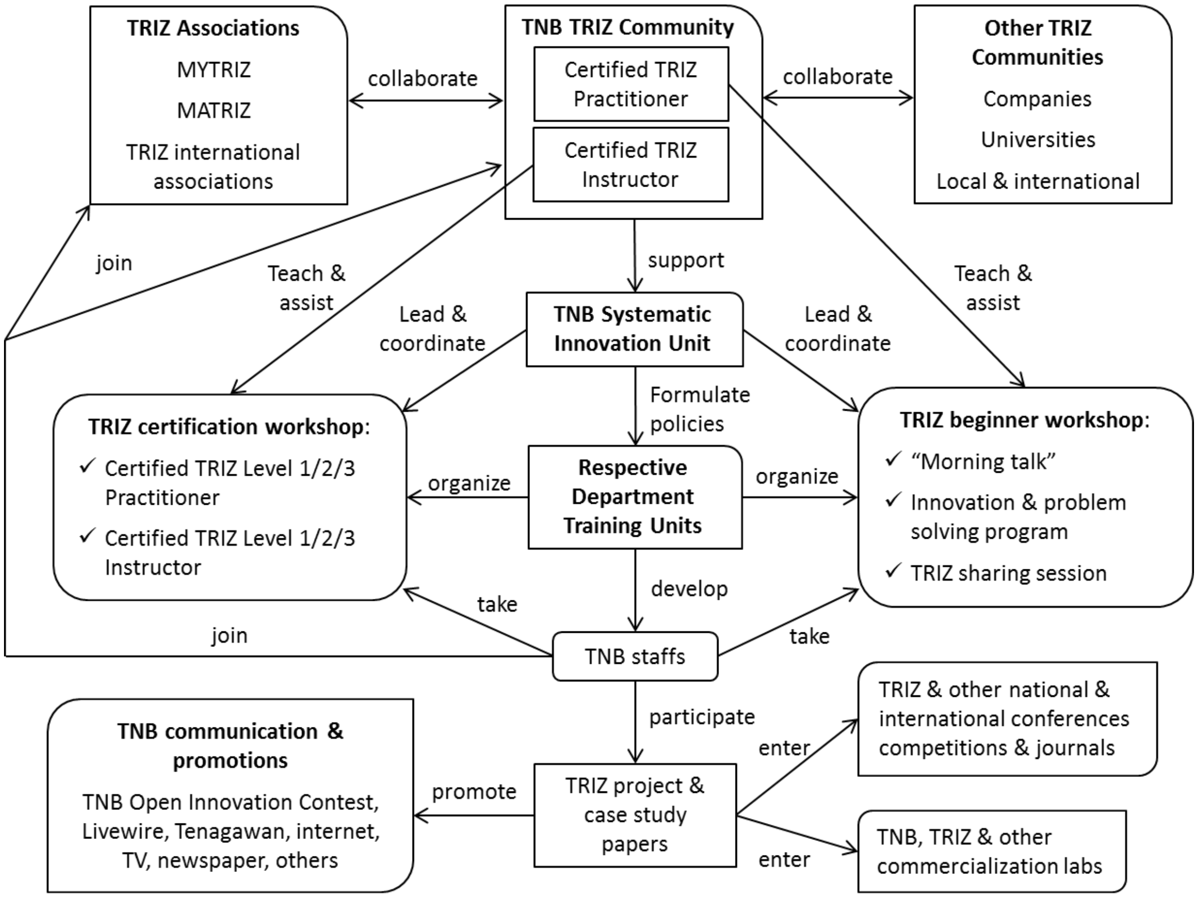


Fig. 3. The proposed TRIZ program to inculcate a sustainable innovation culture in TNB

Certified TRIZ Practitioners who have developed a strong interest and passion to continue learning, using and sharing TRIZ with others would voluntarily join the TNB TRIZ Community which has already been established. Passion that includes "motivating, engaging and listening" rather than expensive perks is believed to be the factor that fosters a culture of innovation [9]. The TNB TRIZ Community promotes and supports the TRIZ systematic innovation framework and program in a bottom-up approach and is championing the learning, using and sharing of TRIZ to inculcate an innovation culture in the company. The TNB TRIZ Community has been closely collaborating with the Malaysia TRIZ Innovation Association (MYTRIZ) and other TRIZ Communities in other organizations. The next step is to collaborate with TRIZ associations in other countries to learn from their experience to further improve the implementation of the TRIZ program in TNB.

Having personally observing many TRIZ Practitioners of not applying TRIZ in their work, an essential component has been included in the proposal which is the TRIZ innovation project. This is also because it may be challenging to demonstrate the great potential of TRIZ in just one workshop and at the same time having to overcome the resistance of adding another tool to the well-established toolkits in a company [10]. The TRIZ innovation project is a workshop that is conducted within 1 month after a beginner and certification workshop. During the project, participants will have to apply TRIZ to solve an actual problem that they are experiencing in TNB. Experienced TRIZ Practitioners and Instructors are the facilitators and the interaction between facilitators and project participants to solve actual problems using TRIZ would continue later to solve other problems that they are facing at their respective workplace. This would result in a continuous cycle of learning, using and sharing TRIZ in TNB that promotes an innovation culture that is sustainable.

The proposed TRIZ systematic innovation framework and program would not be complete without a top-down approach from the management through a proposed TNB systematic innovation unit. TNB need to come up with company policies to support and encourage innovation among employees. For example 3M which prides itself as fostering a “culture of innovation” strongly encourages their employees to innovate by allowing them to spend 15 percent of their time on projects and research that are not within their core responsibilities [7]. The TNB systematic innovation unit needs to manage the establishment of the TRIZ systematic innovation framework and program. It is anticipated to be critical in the first few years to overcome any psychological inertia among TNB employees and to introduce necessary changes to any established work routines and processes.

The case studies of TRIZ innovation projects and other TRIZ solutions to daily problems in TNB can be used to enter the TNB Open Innovation Contest, shared through national and international TRIZ conferences, competitions and journals; and promoted through TNB and public communication channels. This is an opportunity for TNB to motivate and reward staffs to continue learning, using and sharing TRIZ. Outcomes having commercial potential would be registered for intellectual property and considered for entry into the TNB, TRIZ and other commercialization labs and projects.

The expected outcome of the proposed TRIZ systematic innovation framework and program is the regular graduation of TRIZ Practitioner, Instructor and Specialist and for the exceptional ones to become TRIZ Experts and Masters. Those who have developed a strong passion for TRIZ will join the TNB TRIZ Community to continue learning, using and sharing TRIZ among TNB staffs. They will champion the TRIZ systematic innovation framework and program to come up with innovations and in the process inculcate an innovation culture in TNB. The participation of TNB staffs in conferences and competitions will show case innovations and innovation initiatives in the company. This would promote TNB as an innovative company and eventually to be recognized as the most innovative company in Malaysia which is in line with TNB’s tagline – a better, brighter company. Overall, the ultimate outcome will be the promotion and support from TNB to the National Innovation Strategy and National Innovation Model of Malaysia.

3. Conclusions

The TRIZ systematic innovation framework and program proposal has been accepted by TNB as one of the top 20 innovation proposals from over 260 proposals that were submitted by employees in the TNB group of companies in the TNB Open Innovation Contest 2014. The final session in the contest is the TNB Open Innovation Award 2015 on 6th August 2015 during which the CEO and top management of TNB will do a “gallery walk” to meet the top 20 innovators and to view and talk about their innovation. The author has started a bottom-up approach based on the proposal to promote TRIZ to UNITEN students and employees in a number of TNB departments. Experience to-date has indicated that a top-down approach as in the proposal is necessary for an effective adoption of TRIZ by TNB employees. Nevertheless the bottom-up approach by TNB TRIZ Community will continue to promote TRIZ and innovation in TNB and most importantly the continuous learning, using and sharing of TRIZ to inculcate an innovation culture among TNB staffs and UNITEN students.

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TRIZ*fest* 2015

TRIZ, QUALIMETRY AND MARKETING: THREE DIFFERENT APPROACHES TO MEASURING THE COMPETITIVE ABILITY OF THE FUTURE PRODUCTS

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Abstract

Three areas of knowledge – TRIZ, qualimetry, and marketing, independently developed different approaches to determination of the common measure of competitive advantages of artificial products. In the paper, these approaches are compared with each other. The results of our analysis demonstrate that the approaches differ from each other in methods of obtaining the results but use nearly identical qualitative and even quantitative models. We performed the numerical evaluation (assessment) of three characteristics specified in these approaches: ideality (TRIZ), integral quality (qualimetry) and consumer satisfaction (marketing). The results demonstrate very strong correlation between all of these characteristics, which can be easily explained under the assumption that all of them are the measures of the same fundamental quantity: competitive ability of products. Correspondingly, we suggest measuring at least two of them to make the estimates of the competitive ability more accurate, less biased, better reproducible and, finally, better predicting the characteristics of future innovations.

Keywords: ideality, integral quality, consumer satisfaction, competitive ability, kano, triz, qualimetry

1. Introduction

Throughout the whole history of the human civilization, starting from prehistoric times, the technical progress appeared as a process of continuous changes of the artificial products in order to better satisfy human needs. However, only recently the humankind realized the need to measure this progress itself. This need was probably started with the development of some numerical models that mathematically described the change of human population, such as the classical papers of Gompertz (1825) [1], Verhulst (1838) [2] and other scientists. However, these and other measures, such as the gross domestic product (GDP), described the development of civilization or some of its parts rather than artificial products produced by this civilization.

Numerical measures of competitive advantages of products first appeared in marketing and are known as benchmarks [3]. These measures used the category of quality that, in the most general meaning, can be interpreted as some characteristic or set of characteristics of a product or service that bear on its ability to satisfy stated or implied needs [4]. Another common measure of the competitive advantages is known as performance; this word, however, has no more or less common definition and is mostly used just as a common word for various "consumer's" characteristics of products (such as speed, working range, net volume, efficiency, etc.)

Quality, however, covers only one of two essential parts of the competitive advantages; the other part, economy, was traditionally considered separately from the quality. As a result, the use of such measures gave no clear idea of products that were more valuable for the customers and beneficial for the manufacturers. Although everybody knows the expression "price – performance ratio", its numerical measurement is still a difficult problem. Therefore, it is in many cases unclear, what an innovator should improve to get the benefits in the market. An indirect consequence of such situation is the well-known statement that overwhelming majority of new product innovations (by some estimate, from 80 to 95% [5]) fail.

In this paper, we analyse the contemporary concepts to evaluation of the common measure for quality, performance, cost, use, harm and other characteristics that look to be able to evaluate the advantages and disadvantages of products that compete in the market and, as a result of this competition, demonstrate continuous improvement.

2. General characterization of alternative approaches to evaluation of the common measure for advantages and disadvantages of products

2.1. Qualimetry

Qualimetry as a scientific discipline aimed in obtaining the numerical measure of quality of various objects [6] appeared in the USSR in 1960th [7]. It was based on the existing approaches to the quality assessment in different fields of the human activity, including the industry, art, sports, etc. Within the qualimetric approach, the quality is considered as a united measure of all characteristics of the product that are valued by some category of people (stakeholders) having some or other relation to it. The quality, however, does not include the characteristics of economy (cost, expenses, etc.) The integrated characteristic of quality and economy in qualimetry is known as "integral quality".

In qualimetry, the quality of object is considered as a function of its measurable characteristics ([6, 7] etc.) In the most popular variant of qualimetry, so called simplified approach, the quality and integral quality of product can be evaluated as linear functions of particular consumer's parameters by using the following equations (see, e.g., [8]):

$$Q_{int} = W_q Q + W_e E;\; Q = \sum_{i=1}^{Nq} Q_i W_{q,i};\; E = \sum_{k=1}^{Ne} E_k W_{e,k}, \qquad (1)$$

where Q_{int}, Q and E are the integral measures, correspondingly, integral quality, quality and economy; W_q and W_e are their "weight" factors determining the degree of importance; Q_i and E_k are the impacts of i-th (k-th) particular parameter in quality and economy, $W_{q,i}$ and $W_{e,k}$ are their "weight factors", N_q and N_e are the total numbers of the parameters that characterize the quality and economy of the compared products. The values of Q_i and E_k, in turn, can be presented in terms of minimum acceptable value $P_{acc,i}$ and the reference value $P_{ref,k}$:

$$Q_i = \frac{P_i - P_{acc,i}}{P_{ref,i} - P_{acc,i}};\; E_k = \frac{P_k - P_{acc,k}}{P_{ref,k} - P_{acc,k}}. \qquad (2)$$

This formula is schematically illustrated in Fig. 1,a. As we see from the figure, the reference value $P_{ref,i}$ is the maximum "good" value of P_i that is still evaluated by the stakeholders as making some impact to the product's value: at $P_i > P_{ref,i}$, any improvement of P_i does not produce additional impact of quality; for example, increasing the maximum speed of a city car from 200 to 400 km/h does not improve its quality, as far as both of these values are not usable. Similarly, at $P_i < P_{acc,i}$ the value of property is considered so bad that its further worsening does not affect the opinion of stakeholders: city cars with maximum speeds of 50 and 70 km/h are equally bad for their consumers.

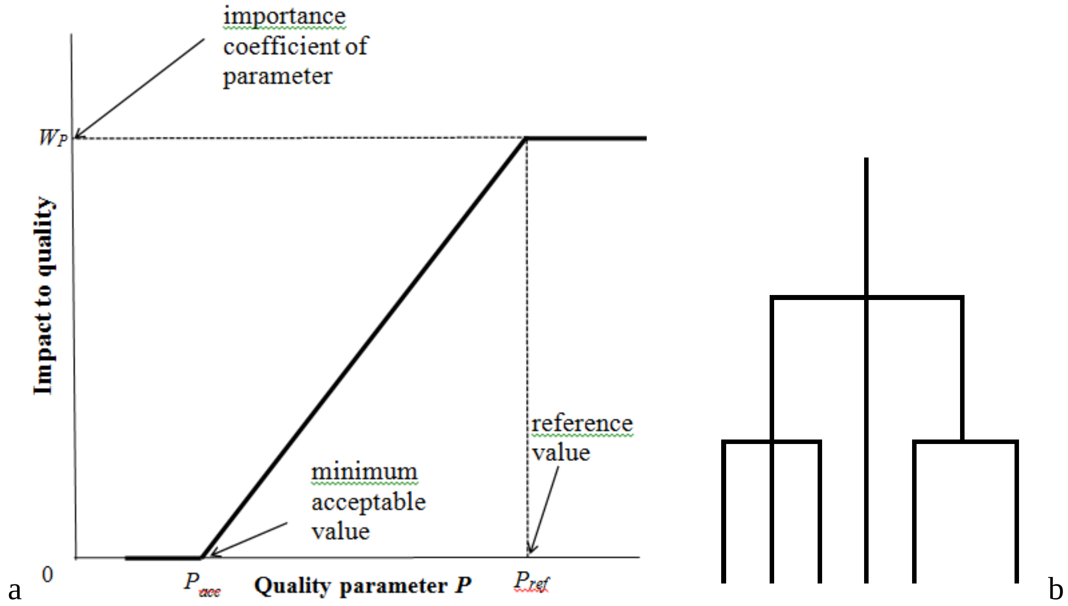

Fig. 1. Schematic view of qualimetric evaluation of the impact of a particular parameter in quality (a) and the tree of properties (b), by Azgaldov et al. [7]

Particular characteristics of quality and economy are named "properties of product" and grouped into the "tree of properties" – a multi-layer tree graph that presents the quality and integral quality in the form of hierarchically ordered branches (Fig. 1,b).

Essentially same, but simplified procedure of assessments is the method of the "analytic hierarchy" suggested by Saati [9]. Other simplified cases of qualimetric models are the "weighted" ratings that are used in gymnastics or free skating, art competitions and other hierarchical ratings.

2.2. Kano model of the consumer's satisfaction

In 1984, Kano [10] suggested a specific model that visually presents the impacts of particular quality or performance parameters to the consumer's evaluation of a product (Fig. 2).

According to this model, the consumer response to the improvements of particular parameters is, in general, non-linear, and the relationship between the measurable ("physical") value and its consumer's evaluation is parameter-specific. According to the Kano model, all consumer's parameters can be divided into five big categories: "**Must-be**" (the customers will accept the product or service if quality attribute is provided; otherwise, they will feel dissatisfied); "**One-dimensional**" (the customers will be satisfied if quality attribute is provided; otherwise, they will be dissatisfied); "**Attractive**" (the customers will be satisfied if quality attribute is provided; otherwise, they will accept the product or service with no dissatisfaction); "**Indifferent**" (the customer satisfaction will not be affected no matter whether this quality attribute is provided or not); and "**Reverse**" (the customers will be dissatisfied if this quality attribute is provided; otherwise, they will be satisfied). Basing on multiple empirical observations, Kano stated that the types of consumer's satisfaction for same parameters of same product tend to systematically change with time: first appearing as an “attracted” parameter, then it becomes “one-dimensional” and then “must-be”.

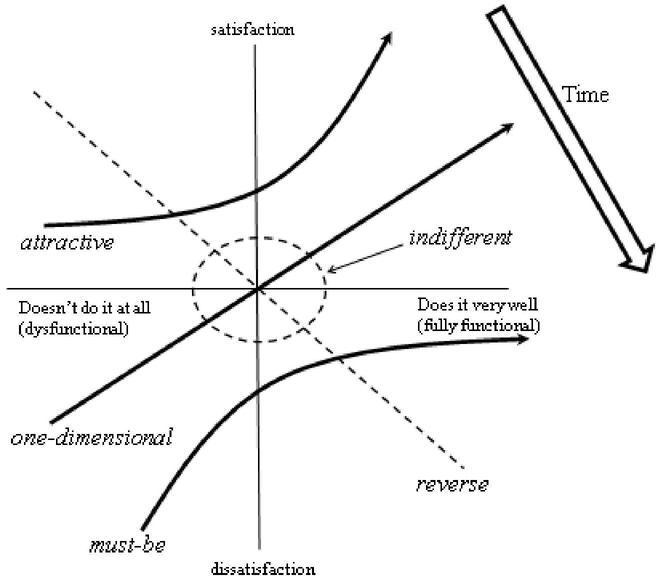

Fig. 2. Schematic view of the Kano model [10]

The Kano model does not provide any direct measure of the importance of particular parameters but gives the common rules concerning their improvements. In very general form, these mean as follows: to improve the “one-dimensional” parameters continuously and the “attractive” parameters as rapidly as possible, keep the “must-be” parameters at their minimum acceptable values, do nothing with indifferent parameters, and reduce the “reverse” parameters which improvements consume extra resources producing only annoyance of the consumers. Thus, attribution of particular parameters of a product to the above-mentioned five categories gives us a *qualitative forecast of their changes in the future products.*

2.3. TRIZ concept of ideality

One of the basic concepts of TRIZ is the concept of ideality. This term means some integral characteristic of an evolving engineering system (e.g. automobile, aircraft, gun, telephone, etc.) that continuously increases with time and describes the degree of proximity of the current state of the art to the “ideal engineering system”. In the first publications (e.g. [11]), the ideal system was considered as a system that has no weight and size and costs nothing, but properly performs its function. In the later publications (the most known of them is [12]), it is considered as an integral measure of all useful and harmful features of a product that can be schematically expressed as follows:

$$Id = \frac{\sum_i F_i}{\sum_i C_i}, \qquad (3)$$

where Id is ideality, $\sum_i F_i$ means “the sum of all useful functions”, and $\sum_i C_i$ means “the sum of all costs”, including the risks, harm, damage and any other negative results produced by the product.

Up to the recent time, the ideality was not considered as a true *numerical* measure of something, but only as a “clear visual image” that specifies the general direction of progress of an engineering system. However, the ideality was considered as something correlated with the *main functional parameter* that growth during the system’s evolution, such as speed of first cars or matrix resolution of first digital cameras. The growth of such parameter is often schematically presented as an S-shaped curve where one can specify several stages of evolution. Martino [14] and other authors suggested various kinds of numerical expressions that, in their opinion, could quantitatively describe and even predict the growth of these parameters with time.

Sood and Tellis [15] showed that a complex parameter of a system expressed as a product (or quotinent) of particular parameters generally better describes the growth curve than each of these parameters itself. Kynin et al. [16] justified that this complex parameter should express the *contradictory* parameters of an evolving system. Priven and Kynin [17] suggested the formal approach to evaluation of such complex parameters.

Lyubomirskiy [18] suggested a non-linear form for the complex parameter of ideality that, in his opinion, expresses the user satisfaction by a product:

$$S = \prod_{i=1}^{N}\left[\left(\frac{P_i - P_{\min,i}}{P_{\max,i} - P_{\min,i}}\right)^{KL/(1-L)}\right]^{1/N}, \qquad (4)$$

where S means user satisfaction, P_i, $P_{min,i}$ and $P_{max,i}$ are current, “minimum” and “maximum” values of the parameter P, and K and L are fitting parameters. The author of [17] considers that the constituents of the complex parameter of ideality in Eq. (4) should be the Main Parameters of Value (MPV) [19].

3. Discussion

If we compare the above-described approach, we see that different authors use same or very similar approaches for evaluation of all mentioned parameters and sometimes even consider them as synonyms. For example, the “user satisfaction” by Lyubomirskiy [18] is considered as a numerical measure of ideality; at the same time, it is essentially similar to the consumer’s satisfaction in the Kano model [10]. The numerical formula of Lyubomirsky (4) actually reproduces the qualimetric formula (2) if we assume that the values of quality parameters in (2) are expressed in logarithmic form (in this case, the product converts to the sum). Considering that in the worldwide literature we found no empirical evidence of preferable form of this equation (linear or logarithmical), this difference seems not significant. In turn, substituting K=1 and L=0 in Eq. (4), we directly come to the approach described in [15] and [16]. In other words, all differences between the described approaches look just “terminological” rather than essential ones, and these independently developed approaches describe the same fundamental entity that is only considered from a little bit different viewpoints.

In our opinion, this entity can be described as ***competitive ability of products***. Indeed, this entity satisfies all requirements to each of the above-described characteristics:

- It continuously grows with time, as well as the ideality in TRIZ: more competitive innovative products continuously replace the old less-competitive ones from the market.
- Like ideality, it represents all consumer’s benefits and losses, according to Eq. (3).
- It expresses the consumer satisfaction, as far as the consumers are those who force the competition of products to go.

- It expresses the relationship between the quality and economy of the market products, like the integral quality in qualimetry, as far as the quality and economy are the main drivers of the market competition.

In other words, the competitive ability of products seems to be the fundamental entity that gives as the link between the quality / performance, cost / price, engineering functionality (useful and harmful functions of engineering systems) and general trends of engineering systems' evolution (TESE) [20]. In terms of competitive ability, these trends can be presented as appearances of a continuous process of overcoming the most critical disadvantages of engineering systems by using the most accessible and cheapest resources [21].

4. Case study

If our conclusions are correct, we should get similar results when we try to apply the above-mentioned approaches to the same evolving engineering system at the same conditions (time of observation, market segment, etc.)

To check this statement, we performed the investigation of a well-known engineering system – long-haul aircrafts manufactured by Boeing and Airbus in 2013. According to http://www.aircraftcompare.com (accessed at June 6, 2014) the best of these aircrafts were: 330-200, A330-300, A350-1000, A350-800, A350-900 and A380-800 from Airbus, and 737-700, 737-800, 737-900ER, 747-8, 767-200ER, 767-300ER, 767-400ER, 777-200ER, 777-200LR, 777-300ER, 787-8 and 787-9 from Boeing. In the Web sites of manufacturers (http://www.airbus.com and http://www.boeing.com) and public databases (http://www.airlines-inform.com/commercial-aircraft/ and http://www.aircraftcompare.com) we could select 10 numerical characteristics that were available for all of above-mentioned aircrafts: fuel consumption, maximum flight range with full load, fuel on board, maximum passenger capacity (for III class), maximum cruise speed, maximum payload, minimum landing distance, minimum runway distance, maximum altitude and engine power. The market prices of the aircrafts were taken from the Web sites of their manufacturers accessed in 2013.

The above-mentioned data were processed by using three alternative approaches: TRIZ benchmarking based on MPV as described in [19], qualimetric assessment of the integral quality according to [7], and index of the competitive ability as described in [17]. Therefore, we determined three characteristics: ranks of MPV parameters according to [19], numerical values of the integral quality according to [7], and competitive ability index according to [17], each of them being determined for each of the compared competitive products. Then we analyzed the correlations between these three characteristics.

As a result, we found that the qualimetric integral quality and competitive ability index demonstrate the linear correlation with each other with the correlation coefficient +0.95, and both of these values have close correlations with the results of ranking by using MPV (Spearman's rank correlation coefficients +0.78 for the integrated quality and +0.84 for the competitive ability index). The strongest of these correlations, between the competitive ability index and integral quality, is graphically presented in Fig. 3.

Therefore, the empirical investigation is in accordance with our assumption that all of three values – MPV rating, qualimetric integral quality and competitive ability index, characterize the same fundamental entity – the competitive ability of the market products.

In this case, we can suggest the combined approach that includes all or, at least, several of these methods in order to avoid biased / subjective conclusions and obtain objective, reproducible and reliable final results.

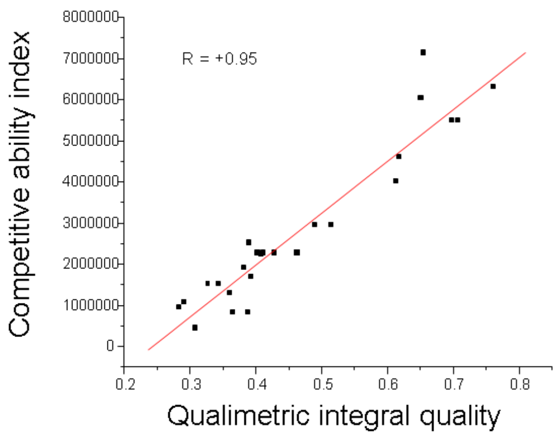

Fig. 3. Comparison of qualimetric integral quality [7] and competitive ability index [17] for the best long-haul aircrafts manufactured in 2013, calculated from the publicly available data (see the sources in the text). Points correspond to different aircrafts.

5. Conclusion

The results of analysis of three approaches to evaluation of advantages and disadvantages of artificial products independently developed in different knowledge areas – economy, marketing and engineering, demonstrate that all of these approaches actually describe the same fundamental entity: the competitive ability of the artificial products. This characteristic is responsible for both engineering and marketing properties of the competing products and determines the qualitative and quantitative trends of their evolution.

As an empirical evidence of this situation, we observe virtually identical qualitative representation and even quantitative formulas used for evaluation of all of these characteristics. Our case study confirmed than, being applied to the same engineering system at the same conditions, all of these approaches give very similar final results that are nearly independent of the used methodology (expert or non-expert methods) and the viewpoint (from the consumer’s or manufacturer’s site).

Basing on the obtained results, we can suggest combined approach that includes several independent evaluations of the competitive ability of a considered family of products. We suppose that such an approach could make the results of evaluation / assessment more reliable, less biased and better reproducible.

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TRIZ*fest* 2015

TRIZ-BASED CAUSE AND EFFECT CHAINS ANALYSIS VS ROOT CAUSE ANALYSIS

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Abstract

This article represents a comparative study of the benefits and shortcomings of two analytical tools widely adopted in industry: Root Cause Analysis (RCA) tools and Cause and Effect Chains Analysis of disadvantages (CECA) that is used in modern TRIZ. Both RCA and CECA are aimed at identifying the deep underlying causes (called ‘root causes’ in RCA and ‘key disadvantages’ in CECA) of a target problem; both employ cause-effect analysis for this purpose, which sometimes leads people to think that these two approaches are essentially the same. There are, however, significant differences in how CECA and RCA are performed, which allow CECA to avoid the shortcomings of RCA and generally make it more robust than RCA. In this paper, the author is trying to highlight these differences and show the advantages of CECA.

Keywords: Cause and Effect Chains Analysis, CECA, key problems, Root Cause Analysis, RCA, root causes, TRIZ, TRIZ tools

1. Introduction

Root Cause Analysis (RCA) [1] is a structured methodology that (1) identifies underlying root cause(s) responsible for the target problem and (2) develops corrective actions aimed at eliminating the root cause(s).

In this paper, we will focus only on the cause-effect analysis tools aimed at identifying root causes through the construction of cause-effect chains. These tools in the RCA are [1, 2]:

• Cause-and-Effect Charts (also known as Fishbone diagrams or Isikawa diagrams)

• Five Whys (also known as Gemba Gembutsu) analysis

• Fault Tree Analysis (FTA).

Since Fishbone diagrams do not show all cause-effect relationships contributing to the target problem, they are not very helpful in understanding the nature of the problem. Therefore, this paper will focus on RCA’s most useful cause-effect analysis tools: the Five Whys and FTA.

Both the Five Whys and FTA involve building cause-effect diagrams that link target problems with their direct causes and, further down the diagram, with root causes.

At present, the RCA is widely used in industry not only by itself, but also as a critical part of the Six Sigma approach [3, 4] where it is used at the analytical stage of the DMAIC (Define, Measure, Analyze, Improve, Control) process. However, RCA has important inherent shortcomings that reduce its efficacy and limit its applicability to analyzing and solving problems only in relatively simple systems [5].

Modern TRIZ, e.g. GEN3 TRIZ, also has a tool, the Cause and Effect Chains Analysis (CECA) of disadvantages, aimed at identifying underlying key disadvantages and the key problems [6] that are aimed at eliminating the key disadvantages. At first glance this tool may look similar to that of RCA, which often causes the misconception that CECA and RCA use essentially the same approach and that a 'key disadvantage' is just a synonym for 'root cause', which, in fact, is not the case.

In this paper, the author is trying to highlight the differences between CECA and RCA and to show how these differences allow CECA to avoid the shortcomings of RCA.

2. RCA and its shortcomings

In RCA, a root cause is considered to be the basic reason behind a target problem or undesirable event (also called 'non-conformance'). It is the contributing factor that, if removed, will eliminate the undesirable event or problem and prevent it from recurring. Root causes in the RCA are always at the end of cause-effect chains.

In order to identify root causes, either the Five Whys analysis or FTA (Fault Tree Analysis) is applied. These analyses are done by continuously asking the question "Why?" or "Why did this happen?" starting from the target problem and continuing through a few levels of intermediate causes until the root cause is identified.

The Five Whys suggests asking this question at least five times assuming that by the fifth "why?" you will normally arrive at the root cause. In practice it may be necessary to ask "why?" more than five times, and sometimes less than five. This analysis is simple and straightforward, but its applicability is limited to relatively simple target problems.

The FTA analysis is more sophisticated and has detailed rules and instructions [7], which allow for building branched cause-effect chains (fault trees) that include "AND", "OR", and other logical gates linking all causes to the target problem. The rules cover all steps of analysis including (1) how to identify causes (faults or failures); (2) how to link them in a fault tree using logical gates; (3) to what depth/level of details the analysis should be done; (4) where to terminate the fault tree.

As the FTA is a well-developed tool, it is included in the industry standard SAE ARP 4761. This analysis is applicable to more complex engineering systems than Five Whys and in many ways is closer than other RCA tools to the CECA. Nevertheless, even for complex systems, most RCA practitioners prefer to use the simpler Five Whys rather than FTA.

The RCA approach to identifying root causes is presented by a simple case study shown in Fig. 1 and Fig. 2:

• Fig. 1 illustrates a target problem arising when hollow bricks are drilled by a rotary hammer drill designed to drill concrete. As shown in Fig. 1, two types of failure may occur during this operation: (1) a big crater is formed at the end of the drilled hole; (2) the entire wall of the brick is destroyed. Either failure makes it impossible to install a screw anchor in the hole tight enough, which is the target problem in this case study. Fixing this problem at the construction site takes too much time; using separate drills for concrete and hollow bricks eliminates the problem, but doubles the load that a construction worker has to carry and increases cost.

• Fig. 2 shows how the RCA has identified the root cause for this target problem by asking "why?" in five steps. (Comment: the Five Why analysis and the FTA yield the same result in this particular case.) As shown in Fig. 2, the identified root cause is 'lack of impact energy control', which results in too strong impact delivered to the brick. Obvious corrective action is to implement some means for controlling the drill's impact energy.

Interestingly, one difference between RCA and CECA is that it is normal for RCA to include 'lack of control' in a cause-effect analysis, but not for CECA as this tool deals only with components already in the system.

Fig. 1. Typical failures that may occur when drilling hollow bricks by a rotary hammer drill designed for drilling concrete

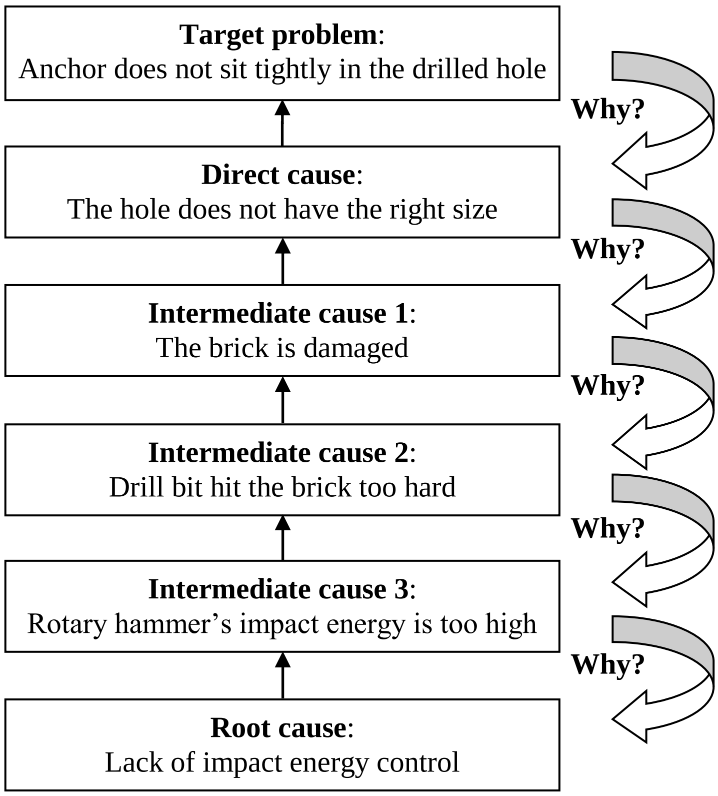

Fig. 2. RCA of the target problem shown in Fig. 1

RCA has been practiced for years. Nevertheless, as shown in paper [5], none of the RCA tools demonstrates a holistic approach nor do they help to understand the problem fully, which is often more important than simply pinpointing a root cause. This means that RCA cannot competently resolve problems in more complex systems.

A few examples of RCA pitfalls listed in the Mini-Guide [2], and their sources, are given in Table 1 below. These pitfalls can easily make RCA fail if, for example, the target problem is incorrectly understood and/or incorrectly defined, or may lead to identifying a suboptimal solution or corrective actions if the most important root causes were not identified.

Table 1

RCA pitfalls and their sources

RCA pitfalls [2]	What causes these pitfalls
Not understanding the problem and therefore not defining it correctly	The main tools used in RCA to understand the problem and system operation are (1) brainstorming, (2) interviews, and (3) expert's knowledge. These tools are too subjective and do not guarantee that all important causes will be captured and included in the analysis.
Not understanding how the system should operate	
Not considering all possible failure modes/causes	Analysis is not deep enough. For example, in the FTA it is not recommended to go deeper than a major component level [7]. This approach does not allow for identifying all causes/failures that relate to subcomponents.
Not identifying all root causes	Cause-effect chains terminate at root causes, i.e. at first encountered causes that, if eliminated, would eliminate the target problem. However, these causes may have their own underlying root causes, which, if discovered, could lead to better solutions.

3. How CECA addresses the shortcomings of RCA

In modern TRIZ, cause-effect analysis is actively used for revealing underlying key problems. A number of TRIZ developers have proposed different approaches [8 - 10] for performing this type of analysis so as to avoid RCA's pitfalls.

For example, the following suggestions were made:

• Terminate branches of cause-effect chains only at the causes representing limitations of the project [8], which guarantees that none of the key disadvantages (in RCA these are "root causes") will be missed;

• Use deeper analysis, i.e. instead of limiting the analysis by a major component level, include causes and effects at the subcomponent level and at the microlevel [8, 9], which helps to discover "hidden causes" that would not be discovered otherwise;

• Find and include causes that appear between two consecutive events [8], which helps to discover hidden causes too;

• In order to reduce laboriousness of the analysis, apply the two previous recommendations only to the causes and effects closest to root causes [8] (i.e. causes terminating cause-effect chains – see first bullet);

• Check completeness of cause-effect chains using the "Parameter-Function Pair Nexus" [9] method, which assumes that cause-effect chains always consist of an alternating parameter-function (or condition-action) type of link;

• Identify technical contradictions (conflicts), which need to be solved in order to eliminate the target problem, by checking what positive effect (if any) each cause in the chain produces

[10]. This approach helps to better comprehend the target problem and the system under analysis.

Most of these suggestions are implemented in GEN3 Partners' CECA, which was developed at the end of the 1990s and has been used successfully in hundreds of consulting projects since then [6]. CECA has become an important tool in GEN3's TRIZ-Assisted Stage-Gate Process [11] for developing new products.

Unfortunately, CECA has been documented and taught only within GEN3 (the author contributed to these activities), and has never been published. In this paper, the author is trying, in part, to fill this void.

Table 2 shows how GEN3's CECA addresses the RCA pitfalls (see Table 1).

Table 2

How CECA addresses RCA pitfalls

RCA pitfalls [2]	How CECA's answer
Not understanding the problem and therefore not defining it correctly Not understanding how the system should operate	The main tools used to define the target problem and to understand the system operation are (1) Function Analysis, and (2) Flow Analysis. Both of these TRIZ tools also utilize expert's knowledge of the system. These tools are much less subjective than that used in the RCA. They guarantee that all important causes/disadvantages will be captured and included in the analysis.
Not considering all possible failure modes/causes	• The resolution (depth) of CECA is flexible: important causes and effects are analyzed deeper than others - at the subcomponent level and microlevel if needed. • Cause-effect chains are built so as to make sure that a parameter-related cause is followed by an action-related cause and vise versa. This ensures completeness of cause-effect chains and identification of all possible failure modes/causes.
Not identifying all root causes	Cause-effect chains always terminate at causes that represent (1) project constraints or requirements, (2) legal limitations, or (3) limitations implied by nature's laws. These causes cannot be eliminated, and, so, they are not further analyzed. This approach guarantees that cause-effect chains include exhaustive set of causes that can be eliminated, and, hence, all key disadvantages (RCA's "root causes") are identified.

The CECA approach is illustrated in Fig. 3, which shows the results of an analysis of the target problem shown in Fig. 1.

As can be seen from Fig. 3, CECA yielded four root causes representing either project requirements or nature's laws (e.g. brick's material properties that cannot be changed). None of these root causes can be eliminated, which is normal for CECA (see the last row in Table 2).

The causes that should be eliminated in order to eliminate the target problem are called in CECA 'key disadvantages'. Each key disadvantage can be easily converted into a key problem aimed at eliminating this disadvantage.

Although the algorithm for selecting key disadvantages from the pool of intermediate causes in the cause-effect chain is out of this paper's scope, it should be mentioned that this can be done using methods similar to those used in the FTA for identifying 'cut sets' [7].

Fig. 3 shows that the following three key disadvantages have been identified:

1. "Rotary hammer's impact energy is too high (for a brick)." This suggests introduction of some means for controlling the drill's impact energy so as to reduce it when drilling bricks.

2. "Impact duration is too short (for a brick)." This means that longer impact would not destroy the brick even if the impact energy is kept high.

3. "Drill bit's penetration speed in the brick is too low." This means that a drill bit penetrating a brick faster than cracks in the brick can propagate, would solve the target problem.

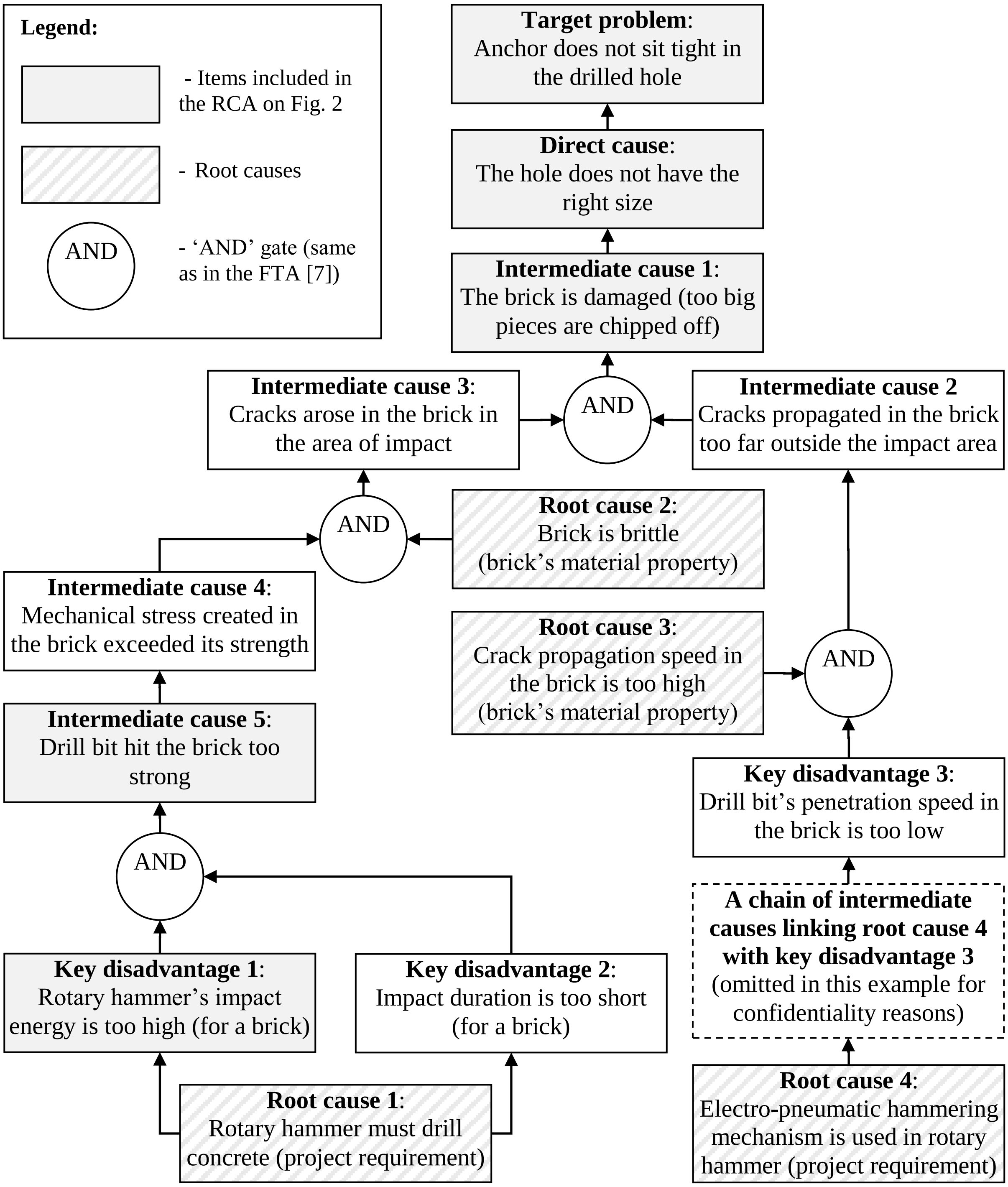

Fig. 3. CECA of the target problem shown on Fig. 1

The first key disadvantage is essentially the root cause yielded by RCA (see Fig. 2). Two others were missed by RCA and discovered by CECA due to a higher resolution of analysis (at the 'cracks-in-the-brick' level) in the "operating zone" (in the ARIZ sense) where the target problem occurs. Eliminating either of these key disadvantages may yield an engineering system with a completely new principle of operation, e.g. a drill with ultra high speed-penetrating drill bit, or a drill with controllable impact duration instead of controllable impact energy.

4. Discussion

Despite the fact that, at first glance, RCA and CECA look similar, they are essentially different in important details, which are summarized in Table 3.

Table 3

Main differences between RCA and CECA

Item	RCA	CECA
Tools that are used to define the target problem and intermediate causes	- Brainstorming - Interviews - Experts' knowledge	- Function analysis - Flow analysis - Experts' knowledge
Resolution of analysis	Not too deep. Normally at a major component level.	Flexible – from major components to subcomponents, and even to the microlevel where needed (e.g. in an operating zone)
Terminating element(s) in a cause-effect chain	Root Cause(s) to be eliminated to solve the target problem	Root Cause(s) that cannot be eliminated as they represent fundamental requirements or constraints of the project
Ability to identify "hidden causes"	No	Yes (ensured by maintaining 'parameter-action' sequence of links in cause-effect chains)
Ability to identify technical contradictions	No	Yes (ensured because the cause-effect chains are complete)

This table shows the higher efficacy of the CECA approach, reflected in the case study presented in Figs. 1 through 3.

5. Conclusions

Based on the results presented in this paper, the following conclusions can be made:

• CECA is an essentially different and more advanced tool relative to RCA. It uses objective modern TRIZ tools, such as Function and Flow Analyses, rather than the brainstorming and interviews used in RCA.

• RCA's root causes are not the same as CECA's root causes, which are absolute terminations of cause-effect chains that cannot be eliminated, nor are they the same as CECA's key disadvantages, because the latter are located above CECA's root causes and in most cases represent deeper level causes than RCA's root causes.

• CECA is superior because it identifies an exhaustive set(s) of key disadvantages to be solved in order to eliminate rather complex target problems.

• Unlike CECA, RCA does not guarantee that all root causes will be identified and, hence, does not guarantee that the most promising solutions will be found.

• Therefore, RCA seems to be suitable mostly for express analyses aimed at identifying near-term solutions for less complex target problems; for more complex tasks CECA is preferable.

Acknowledgements

The author would like to thank Deborah Abramov for her helpful comments and for editing this paper.

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TRIZ*fest* 2015

TRIZ-BASED INNOVATIVE CONCEPT DESIGN OF A SMALL MOBILE HORIZONTAL AXIS WIND TURBINE

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Abstract

This paper presents an innovative concept design of a manual operated small mobile horizontal axis wind turbine. The wind turbine is designed specifically for remote and urban areas to reduce on current high costs of wind turbine components, onsite installation and improve on small wind turbine reliability. CAD models of manual foldable turbine blades, manual retractable wind turbine tower and wind turbine outrigger are designed in Inventor Autodesk 3D software and optimized using TRIZ inventive tools.

Keywords: TRIZ tools, concept design, mobile wind turbine.

1. Introduction

The major cause of current environmental challenges is carbon dioxide emissions from fossil fuel burning power plants and burning gasoline for transportation. Our ever increasing addiction to fossil fuels for generating power releases enormous amounts of carbon dioxide into the atmosphere [1]. Therefore, there is a need for alternative sources of energy to reduce the dependency on fossil fuels. Currently, wind energy is one of the fastest-growing electrical energy sources and it has already shown a high potential of being the source of renewable energy [2]. Generating energy from wind does not pollute the air or produce atmospheric emissions that cause acid rain and greenhouse gases like power plants that rely on combustion of fossil fuels. Also wind energy offers both environmental and economic benefits, and the fuel itself is abundant and free. But the process of harnessing wind energy is expensive and unreliable due to a number of factors such as nature of turbines, site location, turbine installation, maintenance, and cost of turbine components. Modern wind turbines are classified as small, medium, or large turbine. Small wind turbines which are commonly used in urban areas refer to wind turbines rated from 400 watts to 100 kilowatts when running at full capacity. Small wind turbines are ideal to produce clean, emissions-free power for individual homes, farms and small businesses [3- 4].

Currently, small wind turbines installed in built environment are playing a major role in promoting the use of wind power as source of renewable energy. However, most of these turbines face many challenges such as government’s restrictions over the aesthetics, high turbulence intensity caused by tall trees and buildings, lower average wind speed, the perception of potentially high levels of aerodynamic noise generated by the turbines, environmental effects including wild life, shadows and accidents which normally causes injuries and property damage. More still, some landlords in urban areas also do not allow tenants to install wind turbines on their buildings and this hinders non-permanent residents to own wind turbines [5-11]. In order to reduce on the current challenges encountered by small wind turbines in the built environment and improve on efficiency and reliability, this paper developed a simple and innovative conceptual design of a manual operated small mobile horizontal axis wind turbine (figure 1).

Fig. 1. A prototype of a mobile horizontal axis wind turbine

2. Application of TRIZ tools

2.1. TRIZ contradiction matrix

In TRIZ theory, contradictions are regarded as conflicting situations within a system that restrict its effective functionality. Contradictions and conflicts occur when we try to improve one parameter of a technical system which in turn causes another parameter within the same system to deteriorate. TRIZ recognizes two basic types of contradictions, and these are technical contradictions and physical contradictions. In the technical contradictions, the desired state cannot be reached because something else in the system prevents it. For instance, when something gets better, something else gets worse. While physical contradictions are situations where one object has contradictory, opposite requirements. Take an example; one of the qualities of a good product is strength which is good but when the product gets stronger the weight increases which is bad [12-15].

In this research the main target was to optimize the turbine blades into manual foldable blades, the turbine tower into manual retractable tower and the turbine foundation into retractable outrigger. The contradictions that occurred were related to height, strength, weight and support of the turbine. Modern horizontal axis wind turbine relies on the size of the blades. Hence a turbine with larger blade diameter generates much energy from wind. But lager blades make transportation of the turbine difficult on conventional roads and highways. Scondly, harnessing high-altitude clean and smooth winds, the turbine tower must be tall. However, transporting tall towers from place to place on conventional highways seems to be a major issue. Lastly, stability is the most important factor as far as wind turbine system is concerned because the entire upper parts rely on the strength of the base. However, for the case of mobile wind turbine the foundation is likely not to be fixed in one position, the foundation for the mobile horizontal axis wind turbine in this case, is a retractable outrigger that can extend to provide support to the entire part of the turbine system. Still this also poses great challenges towards mobility of the turbine on conventional roads and highways. Therefore, the pair of the parameters that match best are (3 and 38) the length of moving object (improving feature) and the extent of automation (worsening feature).

To resolve the conflicting parameters, TRIZ contradiction matrix was employed in designing both foldable blades with gear coupling, tower sections with rack gear attached on both sides and round pole bracket adapter attached on top of each tower section and a retractable outrigger with multi-stage telescoping hydraulic cylinders. The numbers in the circled cell (1, 4, 7, and 17) figure 2 shows the principles that have been commonly used in solving the occurred conflicts and contradictions in developing a small mobile horizontal axis wind turbine [16-17]. Begin with principle 1, segmentation for designing tower sections, foldable blades and outriggers. Segmentation of parts increases the degree of flexibility in order to ease manual operation, assembling and disassembling process and enabling rapid release of tower section locking pin fasteners. Principle 4, asymmetry was also applied in optimizing tower section's linear movement during extension and retraction. As for the outriggers, it was used in developing special connectors with pin configurations to ensure correct assembling and fastening of the locking features. Nested doll or Russian doll Principle 7 was applied in developing folding and extension mechanism of the tower sections and also designing folding and retraction mechanism of a knuckle joint. Another dimension principle 17 was applied in improving the tower extension, retraction, strength and stiffness. Finally, by applying a pair of four principles we were able to resolve the conflicts and contradictions hence designing a concept of a small mobile horizontal axis wind turbine [18- 21].

In the (figure 2) bellow, the row and columns in the TRIZ contradiction matrix are the numbers of the improving and deteriorated features while the numbers inside the table refer to the possible principles applied in resolving the contradiction when designing turbine folding blades, retractable tower and outrigger.

Improving Feature ↓ / Deteriorated Feature →		1	3	5	13	14	33	38
		Weight of moving object	Length of moving object	Area of moving object	Stability of the object's composition	Strength	Convenience of use	Extent of automation
1	Weight of moving object		14,7,13, 15,	1,2,7 ,17	1,17,3 3			
3	Length of moving object	7,1,15 ,29		7,1,15		1,17,13, 15		1,4,7 ,17
5	Area of moving object	1,7,2, 15	7,15		7,4,9 ,13			
13	Stability of the object's composition	1,4, 17					14,15 ,17	13,17, 2
14	Strength			17,11				4,11,1 3
33	Convenience of use	15,35, 7,14			4,7, 13			13,15, 17
38	Extent of automation	4,7, 13,15	15		4,17,	13,4,11	17, 13,15	

Fig. 2. TRIZ contradiction matrix for turbine blades, tower and outriggers

3. Foldable blades joint for a mobile horizontal axis wind turbine

The manual foldable wind turbine blades are designed to reduce the high costs of turbine components, onsite installation, and maintenance and improve on flexibility of the turbine generator so that it can be mounted on trailer, boat or air craft carrier for transportation without assembling and reassembling which requires extra expenses (Figure 3). In this case, a knuckle joint with gear coupling was designed. A knuckle joint is a mechanical joint used in connecting two rods which are under a tensile load, and when there is a requirement of small amount of flexibility, or angular moment is necessary. There is always axial or linear line of action of load. In this joint, one end of the rod is formed into an eye and the other into a fork (double eye). For making the joint, the eye end of the rod is aligned into the fork end of the other and then the pin is inserted through the holes and held in position by means of a collar and a taper pin. Once the joint is made, the rods are free to swivel about the cylindrical pin. While a gear coupling is a mechanical device for transmitting torque between two shafts that are not collinear. It consists of a flexible joint fixed to each shaft. The two joints are connected by a third shaft, called the spindle. Each joint consists of a 1:1 gear ratio internal/external gear pair. The tooth flanks and outer diameter of the external gear are crowned to allow for angular displacement between the two gears. Mechanically, the gears are equivalent to rotating splines with modified profiles. They are called gears because of the relatively large size of the teeth (Figure 4).

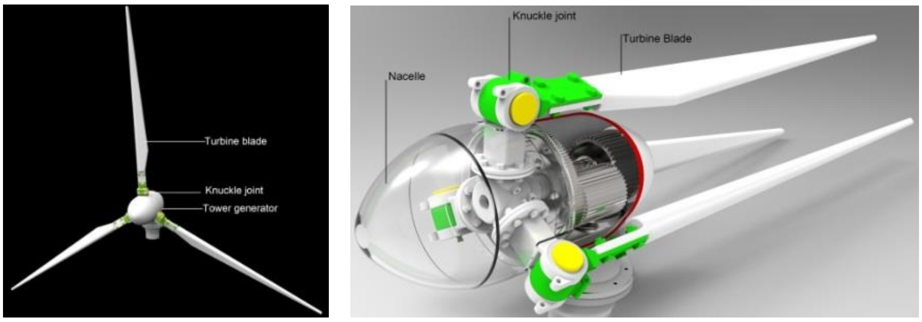


Fig 3. Folded and retracted blades concepts of a mobile horizontal axis wind turbine

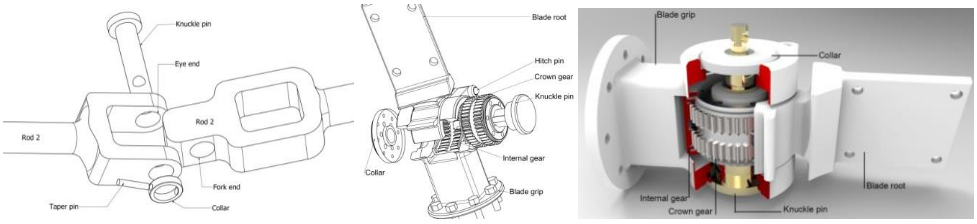


Fig. 4. A conventional sold knuckle joint and a knuckle joint with gear coupling

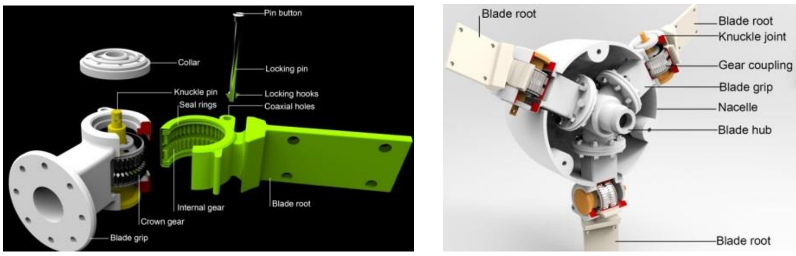


Fig. 5. Folding and retracting mechanism of knuckle joint with gear coupling

3.1. Turbine blade folding and retracting mechanism

An adjustable knuckle joint for a foldable blade includes a pair of coaxial holes on blade grip and blade root. These pairs of coaxial holes are used in connecting and locking the blade root manually to blade grip with hitch pins when wind turbine is in operation. The locking pin has two gib head at end to be slightly squeezed into coaxial holes such that both gib head ends are capable of sliding through the coaxial hole and pivotally retracts at the end of both coaxial holes hence locking the blade (figure 5). While folding the blade, the button on hitch pin is pressed down and springs releases the gib heads to remove the hitch locking pin [22-26].

4. A manual retracted horizontal axis wind turbine tower

The tower is the most important part which is the middle structural system of the turbine. In this innovation, the tower is designed to be manually operated. Each tower section is designed with a pair of rack gear. Rack gear meshes with pinion gear which is fixed inside each tower section brackets and fastened by bolts that are attached to a hand crank. Rack and pinion gears are used to convert rotational motion into linear motion. The hand crank manually rotates a pinion gear which engages the rack. As the pinion gear turns, it slides the rack to move the next tower section (figure 6). The aim of using a hand crank is to minimize the high costs of onsite installation, maintenance and tower components such as the use of multiple telescopic hydraulic cylinders, hoist rope and guy lines (wires) and improve on tower' self-sustainability. A telescopic hydraulic cylinder is used in raising the tower after extension of the tower sections and lowering the tower after all section have been retracted. The main reason for a tilting joint on a manual telescopic turbine tower is to provide flexibility during transportation, maintenance and quick installation. During operation each tower section is extended and fastened by two hitch pins on each side of the tower section and then the whole tower is tilted up vertically at an angle of 180 degrees to its full height of 39.2 feet (11.9 meters) (figure 7) by telescopic hydraulic cylinder attached to the tower base and the tower first section. During transportation of the wind turbine, the tower is tilted down at an angle of 90 degrees and all sections are retracted manually using a hand crank to the height of 12.6 feet (3.84048 meters) (figure 8). In this innovation, the hitch pin is designed specifically to connect two tower sections together when the tower is extended. For coupling tower sections together, two mating tower sections are aligned in the tower brackets manually by hand crank and then held in position by the pin and finally the linch pins is inserted perpendicularly to lock the pin in position (figure 9&10).

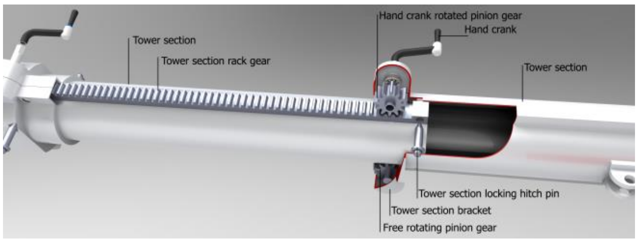


Fig.6. A manual retractable tower section extension and retraction mechanism

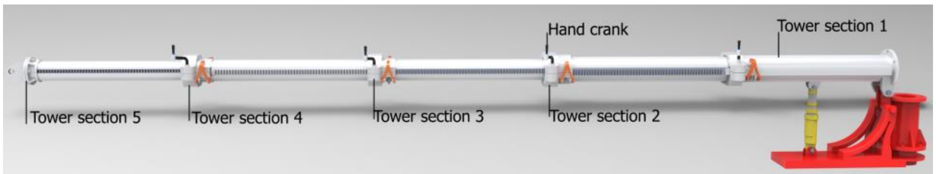


Fig.7. A concept of a manual retractable tower extended and tilted at 90 degrees horizontally by a telescopic hydraulic cylinder

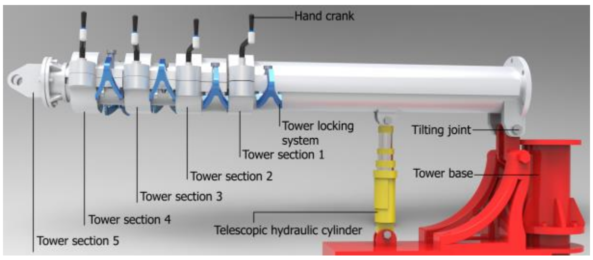
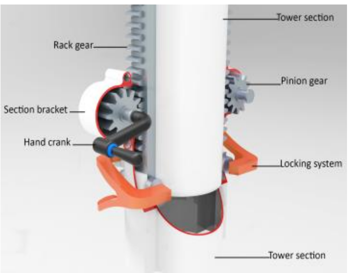


Fig.6. A concept of a manual retractable tower retracted and tilted at 90 degrees horizontally by a telescopic hydraulic cylinder



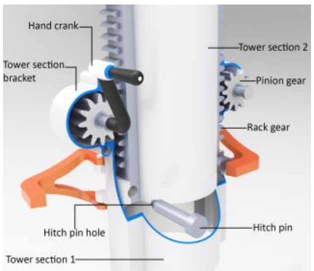


Fig.9. Locked retractable tower section   Fig.10. Unlocked retractable tower section

5. Retractable outrigger for a mobile horizontal axis wind turbine

In conventional wind turbines, the tower base is always made of concrete reinforced with steel bars to provide support to the tower, nacelle and blade system. However, a mobile outrigger is designed as a movable mechanical structure with multi-telescopic hydraulic cylinders to extending outward from the main frame of the trailer to increase stability by providing support to the entire upper parts of wind turbine system. A mobile outrigger is comprised of an elongated main frame and four extensible telescoping outrigger arms which rotate around horizontal axis. These telescopic outrigger arms extend transversely of the main frame and pivotally attached on a horizontal axis for swinging within 180 degrees along the main frame. Each pair of side outrigger arms are rotated and positioned manually, 4 supporters are extendible and retractable by means of telescopic cylinders to convert from a narrower overall width for travel and transportation to a wider outrigger during operation. After extension and retraction, all outriggers' arms are fastened by hitch pins with r-clip inserted to secure them in position [27-33] (Figure 11-13).

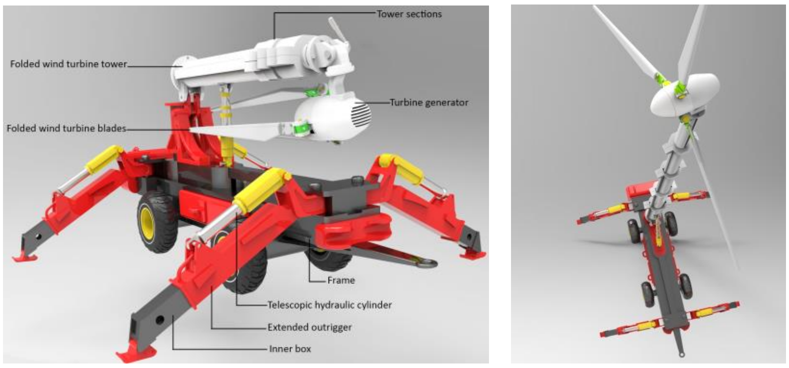


Fig. 11. A design concept of an outrigger for small mobile horizontal axis wind turbine

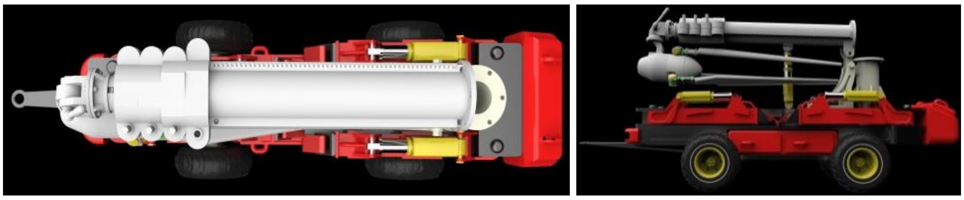


Fig. 12. A design concept of a folded horizontal axis wind turbine outrigger (during transportation)

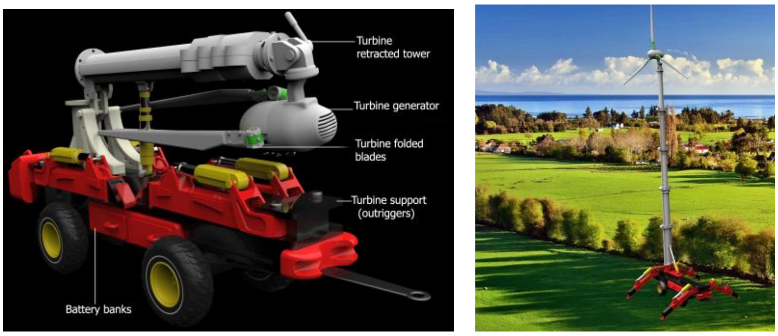


Fig. 13. A design concept of a mobile horizontal axis wind turbine

6. Conclusions

Solving design problem nowadays is getting more and more challenging due current need of efficiency and cost-effective products. To improve reliability, efficiency, flexibility and functionality of small wind turbines, TRIZ the theory of inventive problem solving was considered. The TRIZ principles were applied in concept design of a manual operated small mobile horizontal axis wind turbine components (retractable tower, foldable turbine blades and retractable outrigger). The major aim of this research was to contribute to the existing knowledge by applying TRIZ tools to optimize and modify on existing horizontal axis wind turbine into a mobile horizontal axis wind turbine which can serve as an alternative to conventional diesel generators and able to harness wind energy when temporary or remote power is needed. For instance, during cleanup and recovery efforts following disasters such as hurricanes, earthquakes and tornadoes, military operations, remote outpost and construction sites, water pumping in rural areas, off-the grid monitoring stations, offshore constructions, solar and wind hybrid system, off the grid camping, outdoor social gatherings, parties, picnics and many others. After turbine components (CAD models) analysis, the results based on TRIZ principles shows that the modified mobile horizontal axis wind turbine's foldable tower and retractable outrigger are capable of extending and retracting to the required length and can withstand the rotor system and turbine blades' weight without losing its strength. Hence, this research will provide the ideas and fundamental basics to the future researchers, design and engineers towards the application of TRIZ tools in small wind turbine component design.

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UNIVERSAL UNSOLVABLE PROBLEM AND PROCESS OF RESOLVING IT

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Abstract

What problems should we solve with TRIZ? The problems unsolvable with use of professional knowledge and expertise. Why problem becomes “unsolvable”? Due to incorrect formulation.

These understandings facilitated discovery of universal structure of unsolvable problem. Availability of such structure, in its turn, facilitated discovery of universal process of resolving the unsolvable problems. This process involves four problem-solving stages having same structure; each stage has its specific task. Shift from previous stage to the next one happens only if the previous stage could not produce the satisfactory solution.

Every problem-solving stage includes the following steps: collecting the information; analysis and formulation of Opportunities; idea generation; combining the ideas into Solutions; evaluation and selection of Solutions. Each stage requires minimum information about problem situation and minimum analytical work.

This process is successfully tested at Samsung TechWin and in a Manufacturing 4.0 innovation contest organized by TRIZ France/INSA CVL France & MDBA.

Keywords: TRIZ, problem-solving, unsolvable problem, problem-solving process, analysis, idea generation, solution, evaluation.

1. State of the Art

To solve a problem in any area of human activities, one should perform the same actions: collect the information, develop the model of problem, analyse this model, select the appropriate problem-solving tools, apply these tools to the model of problem, form the model of solution, and evaluate the solution. Accordingly, the ideal goal of any problem-solving approach is reducing the variety of problem models and, accordingly, the variety of algorithms for selection and use of problem-solving tools, without reducing the variety of real-world problems this approach can solve.

TRIZ is not any different. Entire history of evolution of TRIZ problem-solving shows the relentless attempts of finding the universal model of problems TRIZ could solve, as well as the universal algorithms for problem-solving [1]. However, each model and each algorithm had their own limitations. Since Classical TRIZ times, the situation in this area has not changed too much. This fact is based on extant understanding of problems that could be solved with TRIZ ([3], [4], [5]). Accordingly, the fundamental model of “inventive problem” remains the same: *The peculiarity of such problems consists in the presence of a strong contradiction which is impossible to solve by traditional engineering methods* [3].

Recent research reported in this paper revealed the universal model of “unsolvable” problems; this discovery resulted in development of universal algorithm of problem-solving.

2. How Does The Unsolvable Problem Occur?

Unsolvable problem could be defined as a real-world problem that could not be solved by experts in the area where this problem occurred.

Despite of seeming fuzziness, this definition is substantially strict from pragmatic viewpoint, because it provides the clear criteria for separation of “problems that should be solved with TRIZ” from other problems. Moreover, this definition facilitates development of universal model of unsolvable problem, which is shown below.

“Could not be solved” means that all solutions suggested by experts were accompanied by substantial drawbacks. Now, what does “substantial drawback” mean? It means that this drawback represents an insurmountable obstacle to process of performing some job or satisfying some need.

Where did the problem occur? It occurred in some situation. This situation was intended to produce a useful result needed for performing some job or satisfying some need. Then, what is the problem? The problem is that some result of this situation became, for some reason, intolerable. Why? Because it turned into insurmountable obstacle to the process of performing some job or satisfying some need.

Then, why did the problem occur? When the situation was purposefully created, it did not involve any problem. Moreover, the experts who created this situation tried to avoid any side effects or problems. However, the problem occurred. But why?

Presumably, the reason for problem occurrence was some alteration that happened in this world. Something changed, and situation that worked before without any unsolvable problem went wrong. Where had this alteration happened? If it had happened inside the situation, the experts could’ve revealed and eliminated it. Since they could not eliminate it, the alteration had happened outside the situation, far out of experts’ reach.

Experts, then, had to compensate for influence of this alteration. For this purpose, they tried to modify something within their reach, i.e. within the situation or its close environment. However, every suggested solution had the substantial drawback…

This is the way the unsolvable problem occurred.

3. Universal Description of Unsolvable Problem

This mechanism of occurrence of unsolvable problem provides us with opportunity to describe this problem in some universal format:

> The *Initial Situation* was purposefully created to produce the *Useful Result* needed for performing the *Job-1*.
> Somewhere outside the *Situation* some *External Alteration* happened. As a consequence of this *Alteration*, some output of Situation is now perceived intolerable.
> As a result, the *Initial Problem* occurred. This *Problem* creates an insurmountable obstacle to performing the *Job-2*.
> The experts tried to correct the *Situation* and eliminate the *Initial Problem*. However, the suggested *Preliminary Solution* is accompanied with substantial *Drawback* creating the insurmountable obstacle to performing the *Job-3*.
> What could be done?

This description could be represented by the following visual model (flowchart) [2]:

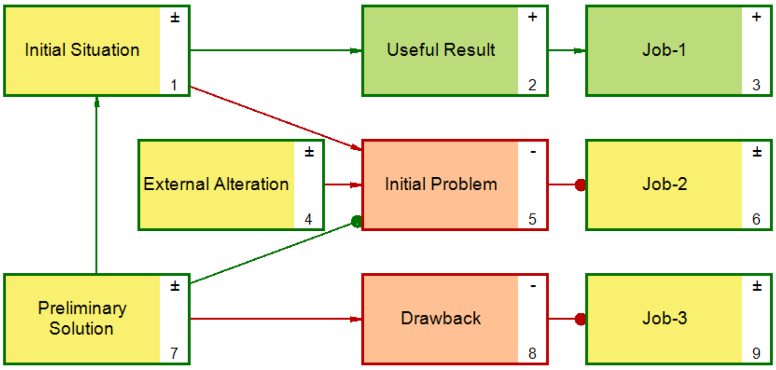

Fig. 1. Model of Unsolvable Problem

This model is so general that it could be applied to any unsolvable problem, including inter-personal and business ones. On the other hand, this model comprises a handful of basic components that are easily related to the actual problem situation; as a result, this model could be easily "translated" to the specific language of real-world problem.

4. Solving the Unsolvable Problem

Altshuller, in course of analysing many hundreds and thousands patents, found out that all problems could be divided into two categories [2]: problems that could be solved by direct use of already known Patterns of Evolution of Technological Systems or their consequences, and problems that are not yet completely formalized. Hence, he divided problems to two classes: typical and non-typical, and said that "problems that are today non-typical, tomorrow, when we reveal the yet unknown patterns, would become the typical ones."

Here, we see the main purpose of search for typical problems: the typical problem assumes the typical process of problem-solving. The Universal unsolvable problem could be solved in the standardized process including four stages:

I. Generate all possible Preliminary Solutions, select the most promising one, and find out its Drawback;

II. Improve the most promising Preliminary Solution by counteracting the Drawback;

III. Improve the Initial Situation;

IV. Make processes of getting Jobs done independent on the problem situation.

This process overtly resembles the Stage-Gate® process. Every problem-solving stage includes the following steps: collecting the information; analysis and formulation of Opportunities; idea generation; combining the ideas into Solutions; evaluation and selection of Solutions. Each stage requires minimum information about problem situation and minimum analytical work.

At the gates between stages, the following decisions could be made: ***go***, e.g. proceed to implementation; ***no go***, e.g. satisfactory solution is not found, and the project team should proceed to the next stage of problem-solving; ***return***, e.g. satisfactory solution is not found, the project team should return to the previous stage and consider other opportunities; and ***postpone***, e.g. temporary stop the problem-solving activities.

The detailed description of universal problem-solving process could be found in [6] and [7]. Here, authors are going to explain this process through the case study.

Case Study: Rice Dryer

Rice should be dried to be stored. Rice is dried in opposing airflow: rice falls down; hot airflow goes upward and removes moisture and dust from rice. Exhaust hot air goes to atmosphere through the long pipe. Exhaust hot air creates a lot of noise, and neighbors complain. However, silencer increases price of rice dryer, and farmers cannot afford it. The following flowchart models this problem:

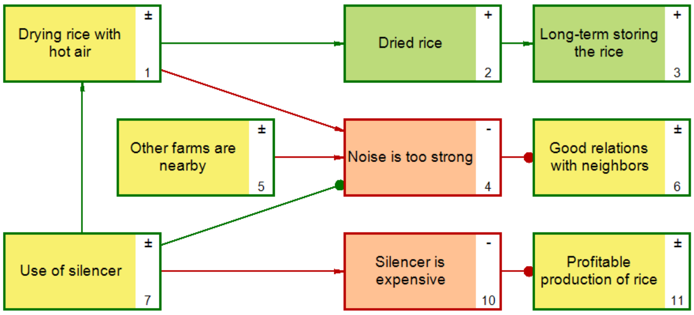

Fig. 2. Model of Case Study

4.1.Stage I. Generate Preliminary Solutions

The Goal of this stage is finding the practically exhaustive set of possible preliminary solutions. At this stage, the model of problem looks like this:

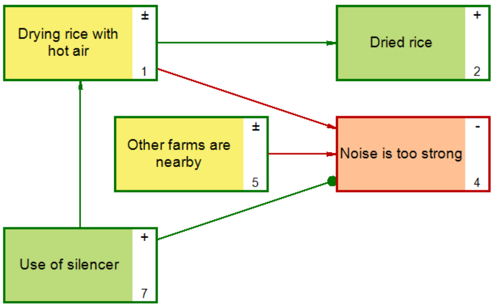

Fig. 3. Model for Stage I

As you could see, the information that should be collected before starting work at this stage is limited to both the information needed to fill the boxes of the problem model and criteria for solution evaluation.

At this stage, one opportunity was formulated: Counteract *Noise is too strong*.

Accordingly, all suggested Preliminary Solutions were aimed at noise reduction. Unfortunately, none of them satisfied the client. Anyway, the most promising and realistic Preliminary Solution still was *Use of silencer*.

In the Universal Problem-Solving Process, all preliminary solutions are assumed as failures; each preliminary solution has severe drawbacks that occur if we try to implement it. Hence, the project team should reveal the drawbacks of selected preliminary solution.

In this case, the major drawback of *Use of silencer* still was its unaffordable cost.

If selected preliminary solution does not have any severe drawback, it is a sin not to take advantage of such luck. In this case, the preliminary solution should become the final solution. If evaluation of this solution is satisfactory, project team should start planning its implementation.

4.2. Stage II. Improve Preliminary Solution

If selected preliminary solution is accompanied with severe drawbacks, it should be improved rather than rejected. The Goal of this stage is to correct the selected preliminary solution, to eliminate its drawbacks. At this stage, the model looks like this:

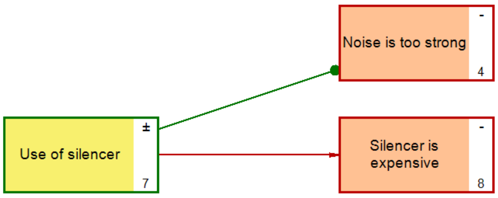

Fig. 4. Model for Stage II

The opportunity formulated at this stage was Counteract *Silencer is expensive*. Accordingly, the suggested solutions were aimed at cost reduction of known design of silencer (some time ago, client's engineers designed silencer to the rice dryer, but market did not accept it due to high cost). The main limitation to cost reduction effort was silencer's efficiency: any simplification of design or manufacturing process should not affect the noise reduction. Unfortunately, this direction did not provide the project team with sufficient cost reduction.

4.3. Stage III. Improve the Situation

If none final solution produced at Stage II is OK for implementation, project team should move to improvement of initial situation. This situation should become insensitive to influence of external alteration that already caused the initial problem. The Goal of this stage is to modify the situation so that, under condition of external alteration, the initial problem could not occur. At this stage, this general model should be used:

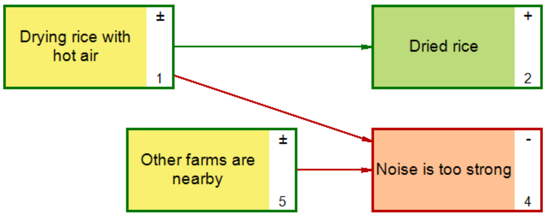

Fig. 5. Model for Stage III

This stage incurs some analytical work. The facilitator should develop the models of situation "as it was intended" and "as it happened in reality." These models should be developed in form of flowcharts that represent events (functions) and links between them.

At the end of analytical work, facilitator should formulate the specific opportunities.

Analysis of problem situation *Drying rice with hot air* revealed several reasons for noise occurrence. However, any changes in rice drying process were prohibited by client: the process was successfully used for many years, and any changes would take too much time for testing. Other changes in aerodynamics of hot air flow inside the rice dryer, as well as in the exhaust pipe, have not provided for any successful solution.

As a result, the project team decided to proceed to the Stage IV, because "technological" problem-solving has not produced the solution worth the implementation effort.

4.4.Stage IV. Improve Jobs

If none final solution produces at previous stages is OK for implementation, the project team should stop solving the “problem as it is”, and start providing for performance of jobs affected by problem situation. The Goal of this stage is to find the ways to perform the jobs so that they cannot be affected by problem situation.

Here is the model for this stage of work:

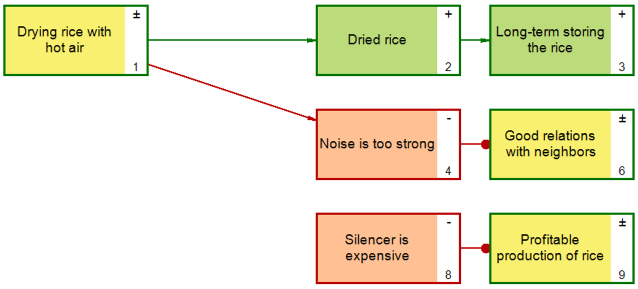

Fig. 6. Model for Stage IV

At this stage, the following analytical work is needed: develop the flowcharts of processes of performing the jobs-1, 2 and 3; model the processes of performing the jobs-1, 2 and 3; reveal which operations of these processes are affected by problem situation; reveal the problems in alternative ways to produce the useful result; and formulate the specific opportunities.

If project team manages to perform the job-3 *Profitable production of rice* so that drawback of preliminary solution *Silencer is expensive* does not affect it, project team should start implementing this preliminary solution *Use of silencer* to eliminate the initial problem *Noise is too strong*.

If project team manages to perform the job-2 *Good relations with neighbours* so that initial problem *Noise is too strong* does not affect it, there is no need to solve the problem as it was stated; project team could keep the situation *Drying rice with hot air* as it is.

If project team manages to perform the job-1 *Long-term storing the rice* without use of useful result *Dried rice* produced by initial situation *Drying rice with hot air* or manages to get this useful result *Dried rice* in alternative way, without initial situation *Drying rice with hot air*, project team could stop performing this situation and forget about initial problem *Noise is too strong*.

Project team started working with Job-3: *Silencer is expensive* counteracts *Profitable production of rice*. Two ideas looked attractive: *Silencer should pay for itself* and *Silencer is combined with rice dryer*. The first idea suggested the following solution: *Hot exhaust air preheats intake air and kerosene (fuel), thus reducing fuel consumption; heat exchange is provided by silencer*. Second idea suggested another solution: *Silencer is embedded in the rice dryer design*. Combination of these two solutions produced the solution for implementation: *Heat exchanger for preheating of intake air and kerosene is embedded in the top portion of rice dryer (thus recycling both heat of exhaust airflow and convection heat of rice dryer); this heat exchanger is designed as silencer*. As a result, noise was reduced to the tolerable level, and fuel consumption was reduced by 15%, thus compensating the cost of silencer.

5. Solution Development

Facilitated project team performs the solution development process in the same way regardless the stage of problem-solving. The solution development scenario comprises five steps: idea generation, idea discussing, development of Idea List, combination of ideas into solutions, and solution discussing.

Project team generates ideas in course of guided, facilitated brainstorming. The project team members, experts in the problem-at-hand and related areas, on their own solve their own problem under TRIZ specialist's facilitation. They generate ideas using TRIZ recommendations that direct their thinking toward the most probable solution areas. Project team members generate ideas either individually or in pairs; the latter is the most efficient way. Facilitator provides each project team member or pair with specific opportunity aimed at solution.

The goal of idea generation is to formulate and document as many as possible thoughts on purposeful modification of resources participating in the problem situation and relationships between them. None of these thoughts should solve the problem. However, various combinations of these thoughts would produce solutions; this job would be done later.

The "guided brainstorming" process driven by simple, but exact TRIZ recommendations was proven as the most efficient way to extract and use the relevant knowledge from brains of subject matter experts. Hence, in this case "brainstorming" does not mean "trial-and-error," rather "knowledge extraction and use."

The goal of combining the ideas (thoughts) into solution is to produce the conceptual solutions resolving the problem-at-hand.

6. Recommended Technique And Tools

The suggested universal problem-solving process is convenient for facilitated work under guidance of TRIZ expert [6]. Facilitator (TRIZ expert) collects needed information, analyzes the problem-at-hand, and formulates the Opportunities (tasks). Then, the project team uses TRIZ recommendations and generates the "raw" ideas (thoughts). The project team could use for this purpose, for example, System of Inventive Principles [8] or other idea-generation tools ([9], [10]). Later, the project team combines these "raw" ideas into Solutions, evaluates these Solutions and selects one worth implementing. If evaluation shows that no Solution meets all criteria, the project team should proceed to the next stage of problem-solving process.

Since the suggested problem-solving process is common-sense based, its structure is similar to other processes of similar purpose, for instance, the Design Thinking process. It means that suggested process and/or its tools could be naturally integrated into other problem-solving approaches.

From TRIZ standpoint, the universal problem-solving process should be compared to ARIZ, due to similarity of purposes. This comparison [11] shows that suggested process is more focused on overtly defined specific directions, and provides for more directions for problem-solving.

This process has been successfully tested in multiple TRIZ projects at Samsung TechWin and in a Manufacturing 4.0 innovation contest organized by TRIZ France/INSA CVL France & MDBA.

7. Results And Discussion

The suggested Universal model reflects the process of occurrence of unsolvable problem: first, the Useful Result is produced by Initial Situation; then, something changes in the world, and Initial Problem occurs; experts try to resolve it, but every time fail. Hence, this model could be applied to any unsolvable problem that should be resolved with help of TRIZ. Since we have the universal model of problem, we can develop and use the universal problem-solving process presented in this paper.

The major benefits of suggested universal problem-solving process are overtly determined directions for finding the solutions, as well as Stage-Gate® process determining the pragmatic sequence of addressing these directions. In this way, suggested process substantially reduces trials and errors inherent to other TRIZ problem-solving processes.

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TRIZ*fest* 2015

'VOICE OF THE PRODUCT' TO SUPPLEMENT 'VOICE OF THE CUSTOMER'

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Abstract

This paper addresses a problem often experienced when generating product ideas. In particular, the ideas generated frequently do not yield successful products. One of the main reasons for this is that the voice of the customer (VOC) is the main input for generating and screening new product ideas. However, the VOC may incorrectly reflect customers' wants and needs, especially in the case of a truly novel product; that is, a product that has never before existed. The author is proposing to supplement the VOC with the more objective 'voice of the product' (VOP), which is derived using TRIZ tools, such as the Trends of Engineering Systems Evolution. The paper includes two brief case studies illustrating the importance of using VOP.

Keywords: Idea generation; new product development; NPD; TRIZ, trends of engineering systems evolution; TESE, voice of the customer; voice of the product.

1. Introduction: VOC is not a perfect tool

Generating new product ideas is the initial and the most critical stage of the entire new product development (NPD) process. Any wrong idea at this stage, if developed further, will result in an unsuccessful product, thereby wasting both the time and the money invested in its development.

Current best industry practices, such as the Stage-gate process [1] and Six Sigma [2], rely heavily on the Voice of the Customer (VOC) as the main input for generating and screening new product ideas. Customers' needs and wishes are further translated into the required functional and technical parameters of the product using, for example, the Quality Function Deployment (QFD) tool [3], which also uses the VOC as an input.

The VOC is usually defined either as a tool/process for capturing customers' wants and needs [4]; or, as the customers' needs and wants themselves [5]. In this paper, the second definition is used, as it is more applicable to the topic here.

VOC is supposed to yield the true needs and wishes of customers to be addressed by the new product once developed. However, being a subjective tool that relies on focus groups, interviews and surveys, the VOC may incorrectly reflect customers' wants and needs.

No wonder that even though gathering the VOC has become a standalone best industry practice, accepted by most companies as the foundation for generating ideas for NPD, there is a lot of scepticism related to its efficacy [6].

There are people who think that VOC is just another term for market research; many people think that VOC simply does not work [7].

This scepticism is backed by numerous examples of incorrect predictions and decisions made with regard to the future of particular new products. Some of these predictions have become famous [8], as, for example:

• “There’s no chance that the iPhone is going to get any significant market share.” (Steve Ballmer, former CEO of Microsoft, 2007.)

• “There is no reason anyone would want a computer in their home.” (Ken Olsen, co-founder and president of Digital Equipment Corporation (DEC), 1977.)

These predictions were made by top managers of large companies who were definitely aware of the VOC collected within their companies. The VOCs, upon which their forecasts were made, apparently were incorrect.

The predictions in these cases relate to completely new products with features and functionality that have never existed before. When developing such products, the risk of capturing the wrong VOC is high and should be supplemented by another, more objective tool, such as ‘voice of the product’ (VOP), as described below.

2. Voice of the product (VOP) and how it supplements VOC

In this paper, the voice of the product is understood as an objective trends/next steps in product evolution, rather like a product’s technical “needs” and “wishes”. Ignoring these trends in the NPD process could well lead to product failure – just like ignoring the VOC.

The idea of using VOP instead of VOC when market information is unattainable (e.g. when customers’ needs are latent or the product is genuinely new) was explored by Jacob Goldenberg and David Mazursky in 1999 [9]. These authors suggested a template approach to identify how a product will evolve in the future, and to predict future market needs.

Using the Trends of Engineering Systems Evolution (TESE) in TRIZ makes it possible to reliably predict how the product’s “wants” and “needs” evolve, and, so, using a TESE-based VOP was proposed [10] as a better input than VOC for NPD.

Indeed, ignoring the VOP could easily lead to the failure of a new product on the market, since the product either will not be able to meet customers’ true needs and wishes, or will be defeated by a more advanced product. On the other hand, if only VOP is used as a guide, other, non-technical, VOC-related factors may also impede the product’s commercialization, no matter how advanced the product is.

Hence, neither the VOC nor the VOP should be ignored in the NPD process. Fig. 1 illustrates how the author is proposing to combine the VOC and the VOP approaches to yield more reliable ideas for new products at the initial stage of the NPD process.

As shown in Fig. 1, a combined VOC+VOP approach involves the following steps:

• Defining the input for NPD. This yields a tentative definition of the target market, target customers for the product and the target product type, which is defined broadly (e.g. ‘a wristwatch’ or ‘a WiFi unit’), without specifying its features in detail. At this step, all input is usually generated by the marketing group of the company conducting the NPD.

• Identifying the VOP. This step yields (1) a specific target product to be improved, (2) the features, functionality and performance that can potentially be achieved. A top-level algorithm for identifying these items is shown in Fig. 1. Details of this algorithm were proposed by the author in 2006 [11] and further enhanced in 2007 [12]. This algorithm ensures that the target product (a) has enough resources for improving its value so as to satisfy the VOC better than competing products; (b) when launched, it will be in demand on the target market and it will remain in demand for long enough to bring profit.

• Identifying the VOC. This is done concurrently with identification of the VOP. At this step, all existing VOC tools can be used. Additionally, the Main Parameters of Value (MPV) analysis [13] is performed in order to discover some latent needs of the customers that the product will potentially be able to satisfy.

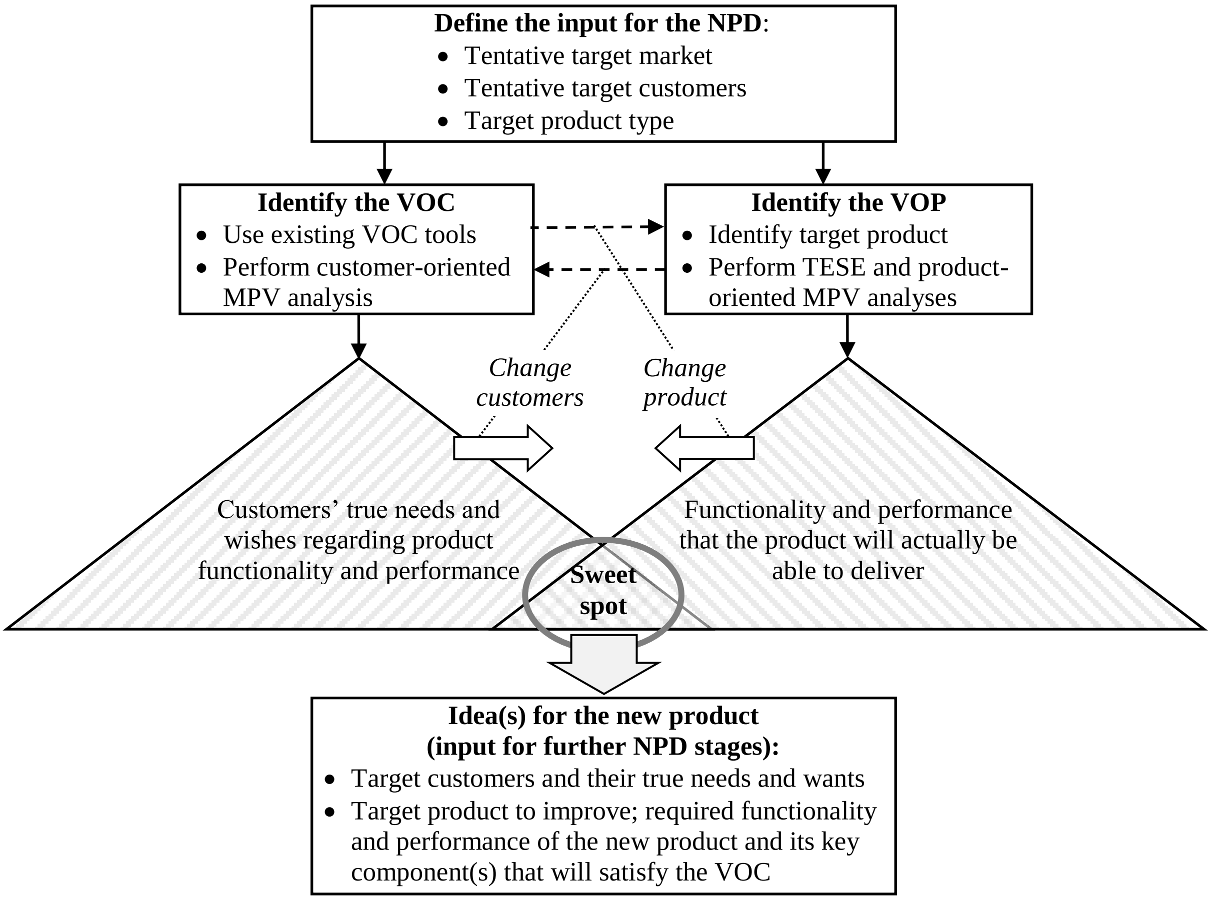


Fig. 1. Combining the VOC and the VOP at the new product idea generation stage

As can be seen from Fig. 2, an MPV analysis plays an important role in identifying the target product by discovering new main (or additional) function(s) that the target product could potentially perform.

Fig. 1 shows that the most promising idea(s) for the new product are located in the sweet spot where the VOC and the VOP overlap. If they do not overlap, then the new product, i.e. VOP, cannot satisfy the VOC and it does not make sense to proceed further with this NPD. Ideally, the VOC and the VOP would coincide fully.

It is important that there is an interaction between the VOP and VOC teams, which is shown by dashed arrows in Fig. 1. This assumes that the VOC or the VOP, or both, may be quickly adjusted (i.e. target product or target customers may be changed), based on feedback from the two teams, so as to make them overlap as much as possible.

This approach significantly reduces the risk that a new product, once developed, will not meet customers' needs and wishes. Additionally, it yields a more detailed idea for a new product than 'VOC-centric' approaches, thus facilitating further new product development from the idea through to a commercial product.

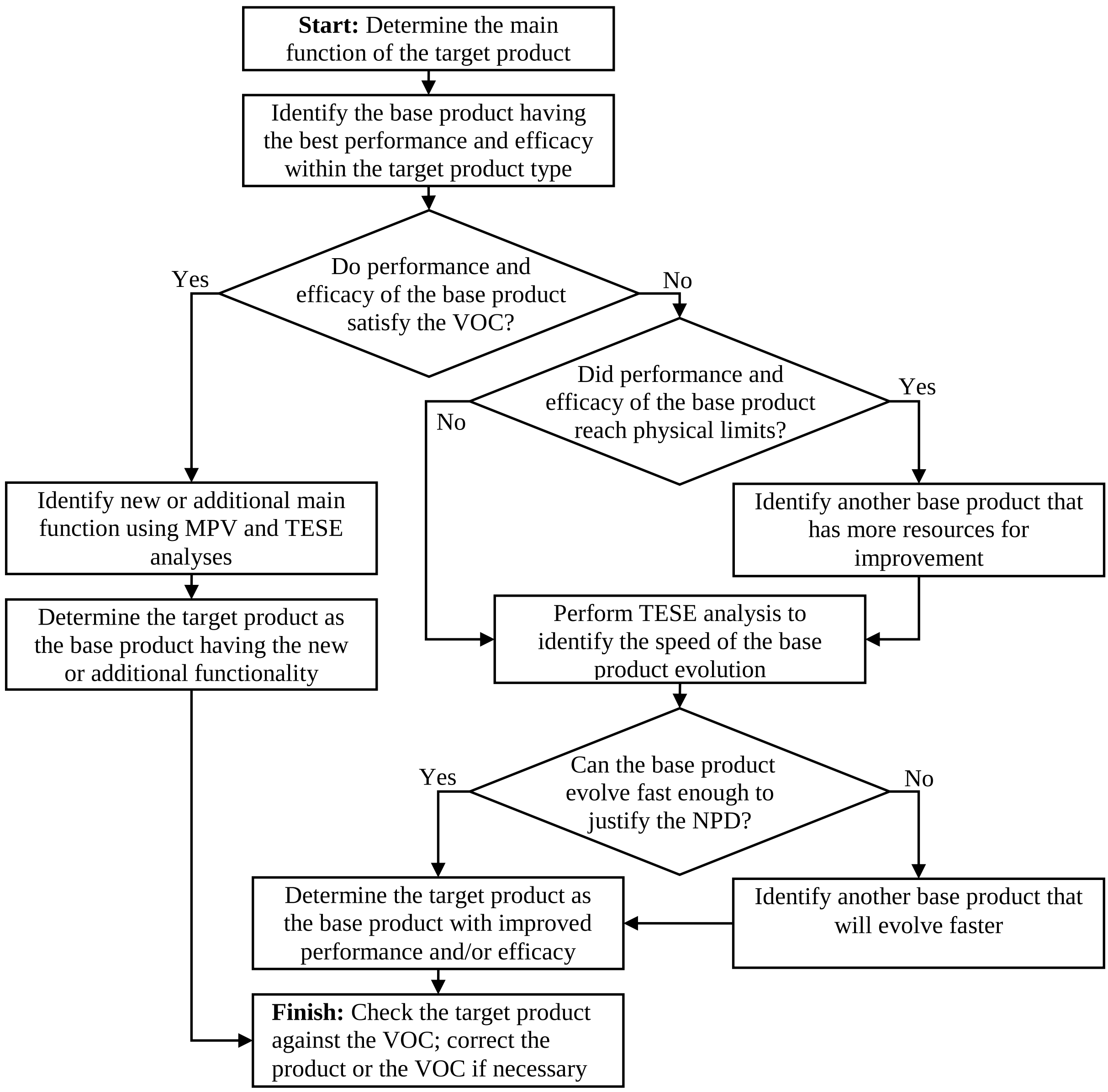


Fig. 2. VOP: top-level algorithm for identifying the target product and its features

4. Discussion and case studies

Supplementing the VOC with the VOP has been successfully practiced in TRIZ-consulting projects and internal initiatives within GEN3 Partners [14]. The importance of introducing the VOP to support the VOC is illustrated by two brief case studies below.

4.1. Case study 1: Smart Watch for athletes and fitness-oriented users

In the beginning of 2008, GEN3 took internal initiative aimed at discovering ideas for a new product. The author was involved in this project as a leader.

The input for this NPD was as follows:

• Target market was tentatively defined as the Russian market

• Target customers - athletes and fitness-oriented users

• Type of new product – a sport wristwatch that can be worn during exercise.

The preliminary VOC captured from athletes, trainers and doctors in sport medicine indicated that all athletes and fitness-oriented users want to make their training as efficient as possible.

For this purpose, athletes were using heart rate monitors (e.g. those by Polar or Suunto) incorporated into a sport wristwatch to correct their load during training and make it more efficient. Athletes and coaches reported that they were happy with their heart rate monitors. So, the VOC seemed to be satisfied with existing products.

In fact, following the algorithm shown in Fig. 2, GEN3 performed an MPV analysis that revealed that a sport wristwatch could potentially measure parameters more informative than heart rate. These parameters were hemodynamics - stroke volume and cardiac output (CO). The VOP, then, was identified as the need to measure these hemodynamic parameters.

The graph in Fig. 3 shows that heart rate always increases as the athlete’s load increases, while stroke volume begins dropping when the load exceeds a certain level. At this time the CO stops growing directly proportional to the heart rate, reaches its maximum, and then actually decreases while the athlete’s load continues to increase. This is a dangerous situation and an athlete could collapse or even die if he or she does not decrease the load immediately.

Hemodynamic parameters (either stroke volume, or CO, or both) make it possible to identify the optimal load, providing maximum training efficiency while avoiding dangerous overload (see Fig. 3). The optimal load for each workout should be set individually as there are many factors affecting it, such as how the athlete slept, how he or she exercised the day before, what he or she ate, etc. A safe, optimal load cannot be calculated based solely on heart rate data.

When the GEN3 team went back to the athletes and coaches who had previously said they were happy with their heart rate monitors, and asked if they would like to have the capability of monitoring CO and/or stroke volume instead of or in addition to heart rate, the respondents became very enthusiastic. They had not known this functionality could be in a sport wristwatch because CO and stroke volume are normally measured with large, stationary equipment. This GEN3-collected VOC satisfied the VOP.

Based on this input, the GEN3 team checked the feasibility of incorporating a hemomonitor in a sport wristwatch and came up with an idea for a new product, shown in Fig. 4.

With this idea, GEN3 approached several Russian investment funds hoping to raise money for further development and commercialization of this product.

Each of these funds collected its own VOC by interviewing fitness trainers, asking them if their clients would buy a sport wristwatch that measures CO or stroke volume.

Their VOC was negative: the trainers said that people are not educated enough to know what these parameters are and why they are important. Also, they said that advanced athletes already have heart rate monitors and are happy with them; other fitness enthusiasts do not need any fitness gadgets; and nobody wants to bother with uploading and analyzing his/her data in the cloud. The overall verdict was that nobody would buy GEN3’s hemomonitor.

As a result, no funds were invested in this product, and the development was cancelled.

Recently, however, fitness gadgets such as trackers and advanced sport watches have become very popular in Russia, and this market is growing rapidly. Users like these gadgets - they upload their data on the Internet, analyze them, share them and compete with other users.

Large companies are currently working on more and more advanced watches for health and sport, e.g. Samsung has recently announced its Simband [15] that is claimed to feature an ability to measure blood flow (i.e. hemodynamic) parameters.

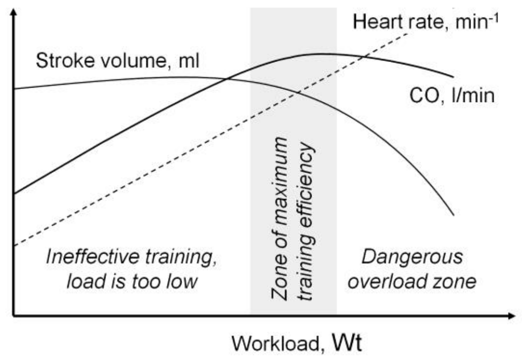


Fig. 3. Cardiac output (CO) and/or stroke volume as a new MPV for athletes

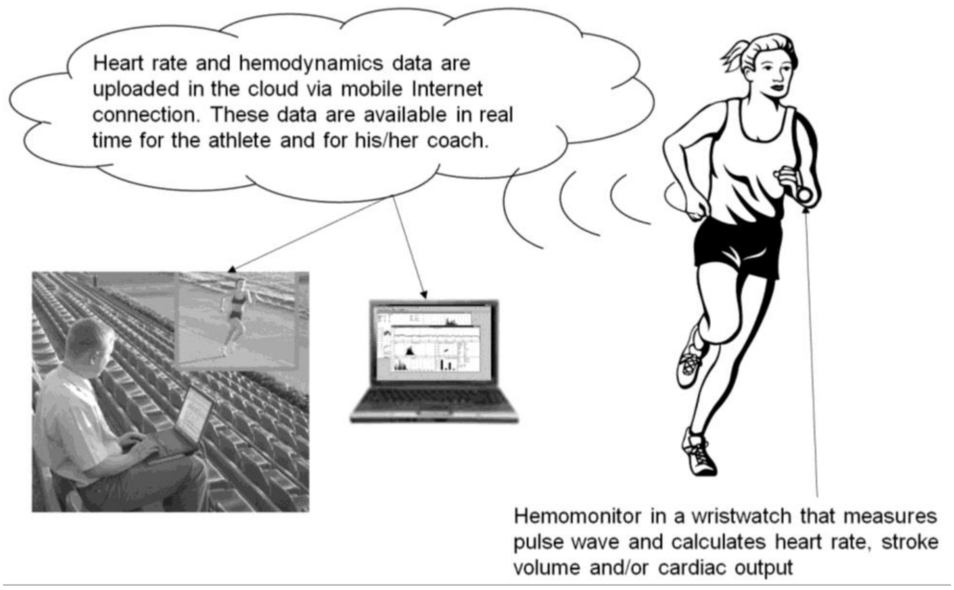


Fig. 4. Idea for a new product: a sport wristwatch that monitors hemodynamics

These facts probably indicate that the identified VOP was correct and should have balanced the contradictory VOC data; nevertheless, the decision to kill the development was based solely on the investors' VOC, which was incorrect.

4.2. Case study 2: Smart antenna for WiFi units

In the beginning of 2000, GEN3 performed a project for a California-based startup company, Airgain, Ltd. The project was aimed at improving performance of a WiFi system, and determined that the key component responsible for the WiFi system performance is its antenna.

GEN3 generated the idea of using a smart antenna (SA) that is a high-gain directional antenna, able to automatically (by using special SA software in the WiFi unit's internal controller) steer its beam towards the direction with the best signal quality.

The identified VOP revealed that in order to deliver the maximum WiFi performance, an SA

1. "Needs" as much space (or area) as possible. Ideally the SA should occupy the whole outer surface of the unit's case;

2. “Needs” to be carefully integrated in the WiFi unit so that other electronic components would not obstruct antenna elements;

3. “Wants” to have multiple antenna elements (some should be oriented vertically; some – horizontally).
This means that the entire WiFi unit should be designed around an SA.

Airgain then made the strategic decision to commercialize the SA as a separate product and sell it to ODMs and OEMs for use in their WiFi devices. However, these customers were more interested in low cost, small size and low profile than high antenna performance, which is quite opposite to the SA’s VOP.

As a result, Airgain had to ignore the VOP and sacrifice its SA performance for the sake of the VOC data. Eventually, most of Airgain’s antennas became non-smart, low-cost, stamped metal elements.

In contrast to Airgain, another company, Ruckus Wireless, which adopted the idea of using an SA in WiFi devices in 2004, focused on developing and selling its own SA-enabled WiFi units, thereby satisfying the VOP perfectly.

The customers Ruckus selected, however, were different from Airgain’s. They were organizations and service providers who needed to provide seamless WiFi coverage within a large area for many users simultaneously (e.g. on university campuses, in stadiums and arenas). These customers were not concerned about the size and height of antennas. Their VOC was concerned about the WiFi performance, which fully coincided with the SA’s VOP.

Both companies, having started their businesses with the same idea, have yielded a sustainable and profitable business. However, as shown in Fig. 5 and Fig. 6, Ruckus consistently generates about ten times more revenue than Airgain. The author attributes this difference to the fact that Ruckus’ approach satisfies both the VOC and the VOP, while Airgain’s meets only the VOC.

These two case studies show that it is typical for the VOC to dominate in the business decision-making process, which may easily lead to rejecting promising ideas for a new product or selecting the wrong customers for the product.

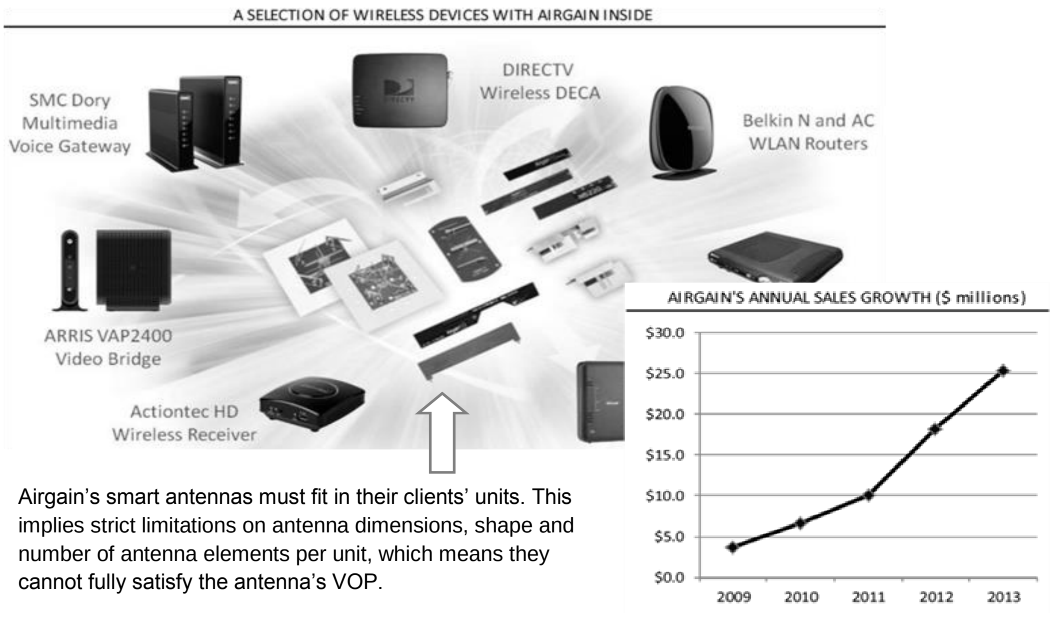
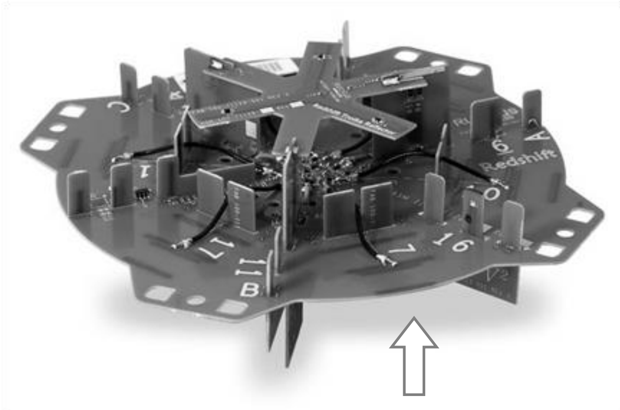


Fig. 5. Airgain antennas and revenue [16]



Compared to Airgain, Ruckus is not so constrained when it comes to dimensions, shape or number of smart antenna elements per unit. This allows Ruckus to satisfy the antenna's VOP fully.

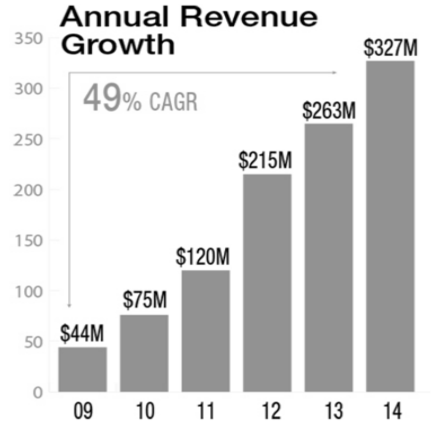


Fig. 6. Ruckus antennas and revenue [17]

5. Conclusions

The Voice of the Customer frequently fails to correctly reflect customers' wants and needs when the product to be developed is truly innovative and the customers have no experience with this product or are not aware that such a product could exist.

To supplement the VOC and avoid rejecting promising ideas for a new product or accepting wrong ideas, a TRIZ-derived Voice of the Product may be used at the initial NPD stages.

The proposed algorithm for identifying the VOP will help in discovering new functionality and features of the new product that correspond to the objective Trends of Engineering Systems Evolution and at the same time satisfy the VOC.

The author believes that the approach described in this paper may represent a useful tool that can make developing and screening ideas for new products much more efficient because it:

1. Promises a noticeable reduction in business risks associated with NPD, which is achieved by satisfying both the VOC and the TRIZ-derived VOP at the same time;

2. Does not require significant effort to implement as it keeps intact the general structure of typical NDP processes, as, for example, it does not affect the structure of the Stage-Gate process – the most commonly used NPD approach.

Acknowledgements

The author would like to thank Deborah Abramov for her helpful comments and for editing this paper.

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TRIZfest-2015 International Conference Proceedings

September 10-12, Seoul, South Korea

Organized by the International TRIZ Association – MATRIZ
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ISSN: 2374-2275
ISBN: 978-0-692-52417-6

Published by the International TRIZ Association - MATRIZ
8946 Wesley Place, Knoxville, TN 37922 USA
www.matriz.org