ISSN: 2374-2275

PROCEEDINGS OF THE TRIZFEST INTERNATIONAL CONFERENCE

THE 10TH INTERNATIONAL CONFERENCE

TRIZfest-2014

THEORIES AND APPLICATIONS

CONFERENCE PROCEEDINGS

September 4-6, 2014, Prague, Czech Republic

Editors:

Valeri Souchkov
Tuomo Kässi

Supported by
The Czech Union of Inventors and Rationalizers

Organized by
The International TRIZ Association – MATRIZ

Proceedings of the TRIZfest-2014 International Conference /
The International TRIZ Association - MATRIZ
Prague, Czech Republic, 2014. – 321 pages.

ISSN: 2374-2275
ISBN: 978-0-692-27134-6

The collection of papers «Proceedings of the 10th TRIZfest 2014 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/education.

All presented papers are peer-reviewed.

Editors:

- Valeri Souchkov, TRIZ Master, ICG Training & Consulting, Enschede, The Netherlands
- Dr. Tuomo Kässi, University of Laapeenranta, Laapeenranta, Finland

Series “Proceedings of the TRIZfest International Conference”, ISSN: 2374-2275

Printed by Tiskárna macek-kusala, Jablonec nad Nisou, Czech Republic

TRIZfest-2014 ORGANIZING COMMITTEE

Organizing Committee Chairman: Dr. Mark Barkan, TRIZ Master.
Co-Chairs of the Papers Review Committee:
- Mr. Valeri Souchkov, TRIZ Master.
- Prof. Dr. Tuomo Kässi.

Treasurer: Mr. Yury Fedosov, TRIZ Master.
Chairman of the Dissertation Council: Dr. Simon Litvin, TRIZ Master.
TRIZfest-2014 representatives in Czech Republic:
- Mr. Pavel Jirman, Association for Invention Development and Intellectual property (ARID).
- Dr. Ivan Mašín, Institute of Creativity and Innovation (IKI) in Liberec.
- Mr. Pavel Dlouhý, Czech Union of Inventors and Rationalizers (CSVZ).

PAPER REVIEW BOARD

Dr. Robert Adunka, Germany
Dr. Iouri Belski, TRIZ Master, Australia
Dr. Bohuslav Busov, Czech Republic
Dr. Marco Carvalho, Brazil
Christoph Dobrusskin, The Netherlands
Dr.Ellen Domb, USA
Dr. Kalle Elfvengren, Finland
Dr. Victor Fey, TRIZ Master, USA
Dr. Oleg Feygenson, TRIZ Master, Russia
Dr. Sergei Ikovenko, TRIZ Master, USA
Dr. Kai Hiltmann, Germany
Juergen Jangtschi, Austria
Len Kaplan, TRIZ Master, South Korea
Dr.Karl Koltze, Germany
Andrei Kuryan, Belarus
Kyeongwon, Lee, TRIZ Master, South Korea
Xavier Lepot, France
Jun-Young Lee, South Korea
Dr. Simon Litvin, TRIZ Master, USA
Alex Lyubomirsky, USA
Dr. Oliver Mayer, Germany
Horst Naehler, Germany
Dr. Toru Nakagawa, Japan
Alexey Pinyaev, TRIZ Master, USA
Valery Prushinskiy, TRIZ Master, South Korea
Dr. Asko Riitahuhta, Finland
Dr. Manabu Sawaguchi, Japan
Pascal Sire, France
Dr. Christian M. Thurnes, Germany
Dr. Tom Vaneker, The Netherlands
Hongyul Yoon, South Korea
Kang Young-Ju, South Korea
Alla Zussman, USA

Dear Friends!

As another annual MATRIZ conference is approaching I am full with excitement and pleasant anticipation of learning new things, discussing the methodology, seeing old friends and meeting new ones.

This year the conference theme is “Theories and Applications”. It is broad and is supposed to embrace new developments, applications, successes and problematic issues of TRIZ and other innovation methodologies.

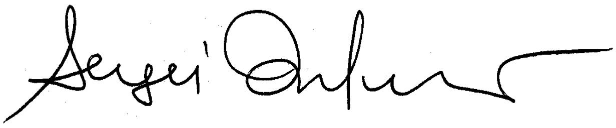
TRIZ has dramatically evolved – the problem solving techniques of classical TRIZ have turned into an innovation platform that encompasses multiple stages of the innovation process. TRIZ tools can be efficiently used for discovering latent market needs, identifying problems that have to be resolved to satisfy those needs and to find practical and commercially viable solutions.

Another strong modern trend is integrating TRIZ with other innovation methods and methodologies. It opens new vistas for TRIZ development and applications, allows to achieve synergy and to intensify TRIZ penetration into new domains.

Our Association (MATRIZ) is getting more and more diverse and multifaceted– both geographically and professionally. It enriches us, makes us better connected with the multidisciplinary innovation community. The coming conference will broaden the process, its papers and presentations from Europe, Asia, America and Australia blend well with the current innovation trends.

I wish you all interesting meetings and discussions, efficient networking, business and theoretical findings, and most of all, to enjoy a wonderful time in the beautiful city of Prague!

Sincerely,



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

Welcome to Prague

On behalf of the local organizing committee I would like to welcome you in Prague and thank the International Association MATRIZ that our capital city Prague was selected as a place of the TRIZfest Conference 2014. This conference is the first international conference on the TRIZ method in the Czech Republic.

Please, be welcome in the land of Charles IV and J. A. Comenius who already in the Middle Ages sought the development of science and teaching methods in the Czech lands. Since that time a lot has changed and the Czech lands have undergone many changes that have shaped the technical thinking of its people.

The origins of the use of the TRIZ method in Czechoslovakia can be dated from the 80s of the last century. It is necessary to mention our doyen Doc. Ing. Vladimir Dostal, PhD, who brought the first information about ARIZ to Czechoslovakia from the former Soviet Union and published his first articles. Very memorable is his meeting with G. S. Altshuller. Since then a series of local workshops were organized, a number of contributions both at home and abroad were published and first lecturers of TRIZ from the former Soviet Union were invited to Czechoslovakia. First lectures of the TRIZ method began at the Technical Universities in Liberec and Brno. The TRIZ method was started to be noticed by the Czechoslovakian industry.

Yet, it was not accomplished in the Czech Republic to anchor the TRIZ method as a standard method for solving of problems associated with technical systems innovation. This fact has many causes such as the development of transnational companies after 1990 with a focus on the low cost and quality assurance, moderated workshops using ad-hoc ideas, reducing of production costs by application of methods of the Industrial Engineering and Lean Manufacturing, non-existing basic publications of the TRIZ in the Czech language and more.

Nevertheless, we believe that in the last five years there has been a turn for the better. There is a need for new radical innovations that cannot be obtained by changing of technology or organization. The share of companies and institutions that seek "stronger problem solving" is growing. We managed to get a few projects funded from the EU funds for universities to support the development of the TRIZ method. We managed to invite a number of TRIZ experts to the Czech Republic also for a longer stay (Sergei Logvinov), special seminars were organised and several specialists were trained to be certified MATRIZ - level 1 to 3.

Furthermore, last year's seminar of Sergey Ikovenko and his lecture for selected managers in our country gave an incentive to organize the conference TRIZfest2014 in Prague. The main theme of the conference - theory and applications - will certainly bring new directions and possibilities of solving technical problems in today's global world, especially for the Czech participants.

We are very thankful for all contributions of the TRIZ specialists at the conference and we strongly believe that the good work of the Paper Review Committee helped to choose the best of TRIZ at this time. I wish to the conference participants a pleasant stay both at the conference and also in Prague and I would like to thank to the all members of the Organizing Committee for assistance in organizing this conference.

Pavel Jirman,
Institute of Creativity and Innovations - Liberec
Association for Invention Development and Intellectual property - Hradec Králové

Dear TRIZfest 2014 participants,

It is a pleasure to announce the proceedings of the 10th International Conference "TRIZfest 2014" which will be conducted on September 4-6 in Prague, Czech Republic. The conference focuses on the following main topics:

- Research in TRIZ
- Development of new methods and tools related to TRIZ
- Sharing experiences with best practices of using and implementing TRIZ
- Case studies with the use of TRIZ.

This year the Organizing Committee has decided to follow the tradition of the previous edition of TRIZfest conference and publish full papers in advance to be available during the conference. It has not been an easy task since the TRIZ community is very diverse and consists of a number of groups which have their own understandings, visions, experiences, best practices. At the same time TRIZfest targets bringing all parts of the TRIZ community together: researchers, developers, practitioners, teachers and consultants to enable effective networking and knowledge exchange. It has been a challenge to find a proper unified format of papers and presentations but we believe we have succeeded and there is still an opportunity to discover even better formats in the future.

It is our conclusion 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 2014 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.

Tuomo Kässi

Valeri Souchkov, TRIZ Master
Co-chair of the TRIZfest 2014 Papers Review Committee
ICG Training & Consulting
Enschede, The Netherlands

Prof. Dr. Tuomo Kässi
Co-chair of the TRIZfest 2014 Papers Review Committee
University of Laapeenranta
Laapeenranta, Finland

INDEX

TRIZfest 2014

A Conception of Modernising LEMACH Designing Methods Using TRIZ Instruments

Maksymilian Smolnik[a]

[a]*AGH University of Science and Technology, Cracow, 30-059, Poland*

Abstract

The work of an inventor is strictly connected with creative thinking and innovative problem-solving that include both imaginary aspects and real (practical) problems. Polish scientists Władysław Lenkiewicz and Bogusław Machowski have widely studied and described how to conduct the designing process in an organised way while elaborating their LEMACH designing methods. However, these methods do not significantly present the creative thinking that has been investigated in detail by Genrikh Altshuller, the author of TRIZ. Because of this state of affairs the conception of integrating TRIZ and LEMACH designing methods, as showed in this paper, was developed.

Keywords: LEMACH methods, designing methods, ARIZ

1. Introduction

Actions taken in order to satiate real (that have already occurred) or hypothetical (expected) needs can often be related to finding new ideas within the designing process [1]. The requirement for conducting this work efficiently leads to the inevitable introduction of methods organising the search for new solutions as well as of methods for conducting the whole designing process. The first mentioned problem is strictly connected with Genrikh Altshuller's TRIZ, whereas the second problem corresponds with designing methods, and in this field the LEMACH designing methods of Władysław Lenkiewicz and Bogusław Machowski can be recalled.

The aim of this paper is to present the LEMACH designing methods themselves as well as to supply a conception of their modernisation with the use of TRIZ instruments.

2. Characteristics of the LEMACH designing methods

The work of an inventor does not only consist in supplying a new idea, i.e. the presented solution has to be introduced in practice (especially in industrial technologies), but first it has to go through the phase of designing and prototyping. What is more, the possibilities of using an idea in any practical way are strictly connected with patent regulations and procedures. The LEMACH methods organise the whole designing process, leading one from indicating the need to preparation of the patent proposals.

Władysław Lenkiewicz and Bogusław Machowski, the authors of the LEMACH methods, were Polish scientists who worked as researchers, lecturers and constructors at Akademia Górniczo-Hutnicza in Cracow (today also called AGH University of Science and Technology), in Instytut Podstaw Budowy Maszyn.

The LEMACH 1 method (elaborated in the late 1960s) was published in 1972. It was designed as a decision-making system for the process of constructing machines and mechanical equipment [2]. The LEMACH 2 method (published in 1975) included a more general approach to the designing process and was to enable solving different problems independently of the content of the analysed task [2].

Another stage in the development of general methods for solving different types of problems was achieved within the LEMACH 3 method (elaborated in 1976). However, as the authors of the methods stated, in some cases when designing work the more general (universal) method may be less useful. Because of this above-mentioned inconvenience, another method, especially for designing machines and mechanical equipment, was developed. The work resulted in the formulation of the LEMACH 4 method [2].

The group of LEMACH methods also includes the LEMACH 5 and LEMACH 6 methods (mentioned, for example: in a paper by [1] from 1982). The LEMACH 5 method was designed to organise designing work being done in order to modernise an existing technical solution or to prepare a detailed technical project when the conception of the solution was already known. The LEMACH 6 method enables one to conduct a designing and research process, especially when designing prototype equipment (which is completely innovative or opens up a new range of solutions) or designing a single (individual) technical object (when much research is needed) [1]. According to the examples mentioned in papers [4,5], the LEMACH 6 method has also been proposed to be used for improvement of the reliability of a technical object.

Though offering guidelines to conduct different designing processes, the LEMACH methods do not investigate in detail the insight, considered as the change of state between the time when there is still no idea and the moment when the idea has already been formed in the mind of the inventor. Creative thinking has been widely investigated by Genrikh Altshuller, who proposed the possibility of controlling the process of searching for an idea [6,8,10]. The widely developed tools that are offered by TRIZ (for example: Algorithm of Inventive Problem Solving, Substance-Field Analysis, Inventive Principles, Ideal End Result, etc. [7]) enable an inventor to methodically look for an idea. When they are used, his or her work is efficiently organised during the phase of searching for the idea. This phase also requires a proper introduction and understanding (or reformulating) of the task and, in the end, leads to an analysis of the obtained results [8,9,10].

3. The LEMACH 3 method

The LEMACH 3 method was designed as a general purpose tool for solving different types of problems, such as technical objects, processes and systems designing. It can be adapted to the specific circumstances of the task being solved. The method may be used both in the continuous development of a technical solution or during work which leads to the final conception that is chosen from a range of possible solutions [2]. The work is generally divided into 5 phases considering different aspects of solving the task. These could be called [2]: formulation of the problem and searching for a conception of the solution (I); optimisation and choosing the conception of the solution (II); elaboration of a preliminary project and its evaluation (III); detail designing and evaluation of the whole project (IV); and verification, research and final conclusion (V). The complete main algorithm of the LEMACH 3 method (with its division into the described five phases) is shown in Fig. 1. The five mentioned phases include 24 steps (shown in Fig. 1), each of which is connected with another activity being performed [2]:

1 - identification of the need
2 - formulating the problem in general and in detail, searching for conceptions for its solution
3 - analysis of the obtained conceptions, optimisation, choice
4 - description of the solution and its characteristics, patent analysis

5 - preparation of energetic, material and personnel data
6 - preparation of economic assumptions
7 - elaboration of a general solution to the problem and a preliminary project
8 - elaboration of guidelines for detail designing
9 - evaluation, reconciliation and approval of the preliminary project
10 - detail designing of assemblies, sub-assemblies and parts
11 - cumulative elaboration
12 - general verification of the documentation
13 - patent analysis of the detail solutions
14 - feasibility analysis and reconciliation of the solution with its manufacturer
15 - costs analysis
16 - final evaluation and decision about implementation of the project as planned
17 - modelling, building the prototypes
18 - elaboration of the prototype research programme
19 - research done on the prototypes
20 - elaboration of the research results
21 - analysis of the research results, project update, elaboration of the list of weak links and the assumptions for modernisation
22 - elaboration of technical data and operation and maintenance manuals (documents)
23 - elaboration of patent proposals
24 - final approval of the project.

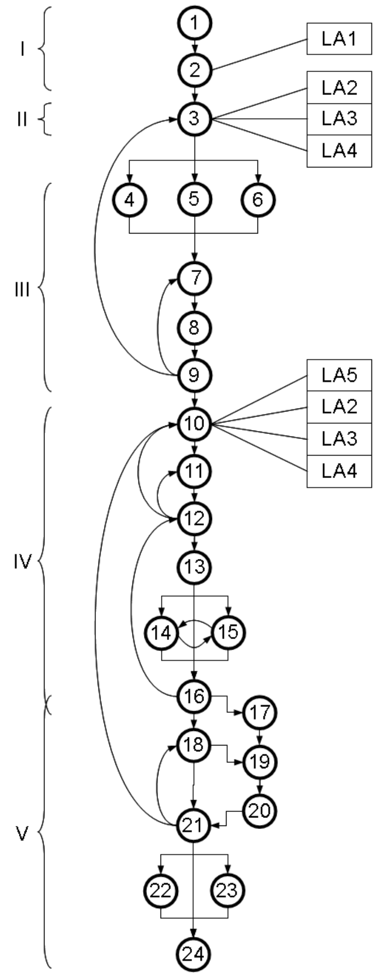


Fig. 1. The main algorithm of the LEMACH 3 method [2]

The main algorithm of the LEMACH 3 method is linked to a number of sub-algorithms (here named LA1 to LA5). Use of the sub-algorithms at proper steps when solving the task was shown in Fig. 1. The sub-algorithms include [2]: formulating the problem and generating conceptions of solving the task (LA1), evaluation of the conceptions of the project (LA2), first type (inter-variant) optimisation (LA3), second type (intra-variant) optimisation (LA4), and detail designing (LA5). Sub-algorithm LA1 was presented in Fig. 2. The numbered steps lead one through [2]:

LA1-1 - general characteristics of the needs in the considered field

LA1-2 - gathering the most important information about the considered need

LA1-3 - formulating the designing problem in general

LA1-4 - considering if it is possible to solve the task

LA1-5 - finding a preliminary conception of the solution

LA1-6 - analysis of the existing ways of satiating the need

LA1-7 - identifying the reason for the lack of satiation

LA1-8 - gathering information and formulation of the detail assumptions

LA1-9 - technical and economic analysis of the possibilities of meeting the assumptions

LA1-10 - formulating the designing problem in detail

LA1-11 - choosing the methods and strategy of devising (creative thinking)

LA1-12 - methodically formulating a number of conceptions for solving the problem

LA1-13 - considering if the number of the conceptions is large enough

LA1-14 - considering if the assumptions can be changed somehow

LA1-15 - partial change of the assumptions

LA1-16 - formulating a supplementary set of conceptions

LA1-17 - organising and describing the conceptions.

The LEMACH 3 method includes guidelines for the complete process of applying a new idea and designing. As the most developed tool (from the group of LEMACH methods) for solving general technical problems in designing and including the aspect of inevitable devising in the designing process, it was chosen to be modernised with the use of TRIZ instruments.

4. Conception of the integration of TRIZ and the LEMACH 3 method

A comparison of the fields mostly considered by TRIZ and the LEMACH methods may lead to the statement that they complement each other. Organising the whole designing process according to the LEMACH methods by filling the phase of the idea search according to the guidelines of TRIZ could increase the value of both tools, especially when they are used in mechanical engineering. This possibility of integration becomes even more visible after considering the algorithmic structure of the LEMACH methods and the presence of the Algorithm of Inventive Problem Solving [7] in TRIZ. The proposed solution is based on the integration of algorithms from the LEMACH 3 method and the Algorithm of Inventive Problem Solving (ARIZ 77).

As was mentioned above, sub-algorithm LA1 is a part of the LEMACH 3 method, which is mostly connected with the search for an idea. Because of this state of affairs, work connected with modernisation of the LEMACH 3 method was done within this sub-algorithm. The modernised sub-algorithm LA1 (now called MLA1) is presented in Fig. 2. The process of modernisation covered:

- rewriting steps LA1-1, LA1-2 and LA1-3 (now: MLA1-1, MLA1-2 and MLA1-3), which had been taken from algorithm LA1 and were not changed somehow
- deletion of step LA1-4, which probably too early (in the whole designing process) addressed the question of the possibilities of solving the task, still without the use of any tools for inventive problem solving
- deletion of step LA1-5, which probably offered a shortcut in the sub-algorithm that enabled one to go further without considering some aspects of the task being solved
- deletion of step LA1-6, which included actions similar to those in step 1.8 of ARIZ 77 (and could increase psychological inertia [7] in this early phase of solving the task)
- rewriting steps LA1-7 and LA1-8 (now: MLA1-4 and MLA1-5), which had been taken from algorithm LA1 and were not changed somehow
- reformulating step LA1-9, which is now called ‘Preliminary technical and economic analysis of the possibilities of meeting the assumptions’ (and presented as MLA1-6)
- reformulating step LA1-10, which is now called ‘Formulating the inventive problem’ (and presented as MLA1-7)
- replacing steps LA1-11 and LA1-12 with steps from 1.1 to 7.2, from ARIZ 77 (which are now steps from MLA1-8 to MLA1-38 in the modernised sub-algorithm) and reformulating step 4.5 taken from ARIZ (now MLA1-30), which is now called ‘Going from the physical solution to the conception of a technical solution’ and was adapted to the structures of the LEMACH 3 main algorithm and the modernised sub-algorithm MLA1
- deletion of step LA1-16, which was considered as including actions performed in other parts of the modernised sub-algorithm
- reformulating step LA1-13, in which now it is considered whether the obtained conceptions are feasible due to the imposed assumptions (presented as MLA1-39)
- rewriting steps LA1-14, LA1-15, and LA1-17 (now: MLA1-40, MLA1-41 and MLA1-42), which had been taken from algorithm LA1 and were not changed somehow
- rewriting the connection between sub-algorithms LA1 (now MLA1) and LA2, as had been proposed originally, in order to preserve the possibility of evaluation when a number of conceptions of a possible technical solution has been obtained.

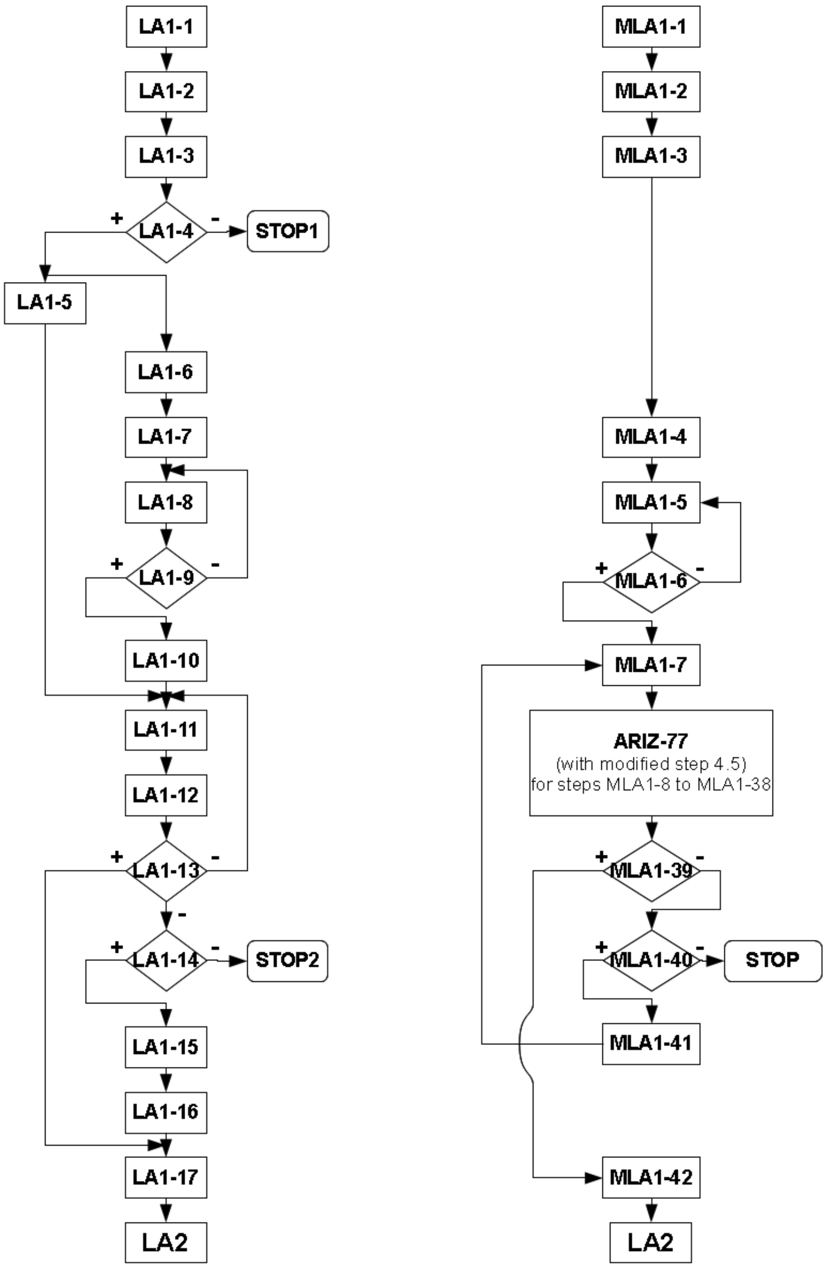


Fig. 2. The original sub-algorithm LA1 [2] and its modernised version MLA1

The possibility of integrating TRIZ and the LEMACH methods, as proposed above, was presented with the use of an example.

5. Example

There is a problem connected with grinding which is considered as an example of using the Algorithm of Inventive Problem Solving (ARIZ 77) [7], as presented in one of Genrikh Altshuller's books [8]. The example allows one to observe proper use of the algorithm while solving an inventive, industrial problem. It was built into the main algorithm of the LEMACH 3 method (supplemented with the modernised sub-algorithm MLA1).

The work (due to the guidelines of the LEMACH 3 method) begins with identifying the need. The mentioned problem is connected with difficulties that occur while grinding a workpiece of a complicated form, especially with concavities and convexities, e.g. a spoon [8] or a lens. In this case the task could come from the cutting tool industry, a household equipment factory or an optical equipment factory. The second step is to formulate the task in general and in detail and to search for a conception of its solution. At this stage, use of the first sub-algorithm (formerly LA1, now MLA1) is suggested [2].

The task may occur in industrial circumstances and, consequently, it may refer to mass production, performed in a number of factories (MLA1-1). It is important to investigate both the technology and the equipment being used (MLA1-2) in order to formulate the designing problem in general (MLA1-3). The need may not be satiated because of a too complicated production method that generates high costs, is time consuming or eventually results in insufficient quality of the products (MLA1-4). When more data are collected, detail assumptions may be stated (MLA1-5). In this case they refer to the lack of being able to use some types of specialised grinding equipment or other production technology [8]. This fact would probably also appear after a technical and economic analysis of the possibilities of meeting the assumptions (MLA1-6), which would abandon some ways of solving the task. Then the inventive problem has to be formulated (MLA1-7) in order to prepare the ground for TRIZ. Subsequent steps include actions organised for the Algorithm of Inventive Problem Solving.

First, a preliminary elaboration of the task is performed within steps MLA1-8 to MLA1-16 (steps 1.1 to 1.9 of ARIZ 77). The main aim of the task is (generally) to transform the production method in order to conduct the process more easily and with better results. Then the work is organised for steps MLA1-17 to MLA1-20 (steps 2.1 to 2.4 of ARIZ 77) when the model of the task is being built. A pair of elements (the spoon and the disk-type grinding wheel) is given in the analysed case. The grinding wheel generally may be used for grinding but cannot be adjusted to the curvilinear surface of the workpiece [8]. The model of the task is analysed during actions taken within steps MLA1-21 to MLA1-25 (steps 3.1 to 3.5 of ARIZ 77). The form of the product must not be changed anyhow, so it is the grinding wheel that should be modified. Due to the Ideal End Result, the wheel should adjust itself to the surface of the workpiece without any harm to the grinding process. Eventually, the physical contradiction [7] may be stated: the outer side of the grinding wheel should be too hard to grind properly and should not be too hard to adjust itself to the surface of the workpiece [8]. This contradiction is overcome within steps MLA1-26 to MLA1-30 (steps 4.1 to 4.5 of ARIZ 77, with the modified step 4.5) and in the end the conception of a technical solution is obtained. The inner part of the grinding wheel could include magnets, whereas the outer part could be made out of ferromagnetic particles (or ferromagnetic particles mixed with abrasive dust). This allows the grinding tool to be hard enough to grind properly and to adjust itself to the surface of the workpiece [8]. Steps MLA1-31 to MLA1-38 (steps 5.1 to 7.2 of ARIZ 77) allow one to evaluate, verify and develop the obtained result as well as to analyse the course of solving the task [8]. Steps MLA1-39 to MLA1-41 include consideration whether the assumptions and requirements are met or could be changed somehow. When there is at least one conception of a technical solution, the first phase of work with the LEMACH 3 method is finished (MLA1-42).

The second phase includes evaluation and optimisation as organised for sub-algorithms LA2, LA3 and LA4. The third phase is connected with defining more detailed parameters and characteristics of the solution, which is gradually developed into the preliminary project [2]. In the analysed case this could be a preliminary project of a modernised grinder with new equipment for the use of a magnetic field in the grinding process. When the preliminary project is accepted, detail designing (and the fourth phase) may be undertaken (with the use of sub-algorithm A5), thus leading to a detailed project of all parts of the machine, along with analysis and acceptation of the whole solution. The last (fifth) phase is connected with research done on the prototypes [2]. The functioning of the prototypic grinder should be verified in practice, in the laboratory and in production conditions. When the research is done and the conclusions are drawn, technical data and manuals as well as patent proposals may be prepared [2]. These will then describe the construction, operation and maintenance of the modernised grinder and will allow the inventor to protect his or her solution in the future.

6. Conclusions

The use of both TRIZ and the LEMACH methods during inventive problem solving (for example: in the designing process and especially in mechanical engineering) extends the range of work done methodically.

The methods and tools used in the designing process should organise the work of an inventor and/or designer but should not prevent him or her from obtaining new ideas [2]. This state can definitely be achieved when TRIZ and the LEMACH methods work together.

The proposed solution could be further developed through introducing another Algorithm of Inventive Problem Solving (for example: ARIZ 85 [10]) into the algorithms of the LEMACH 3 method. Probably also worth considering would be to verify the possibility of introducing the tools offered by TRIZ to other LEMACH methods.

The application of TRIZ instruments in work organised for the LEMACH 3 method provides a broader look into the search for ideas, which is an inevitable part of the innovative designing process.

References

1. Lenkiewicz W., Machowski B. Proceedings of the seminar „Szkoła Metodologii Konstruowania Maszyn", part III, Rydzyna, Społeczny Ośrodek Badań i Studiów, 1982

2.Lenkiewicz W., Machowski B.: Zmodernizowane procedury projektowania i konstruowania LEMACH 3 i 4. Kraków, Instytut Podstaw Budowy Maszyn AGH, 1978

3. Lenkiewicz W., Machowski B.: Metoda projektowania LEMACH 2. Kraków, Instytut Podstaw Budowy Maszyn AGH, 1975

4. Heinrich M. „Badania eksploatacyjne jednostkowych złożonych obiektów technicznych w celu podniesienia ich niezawodności konstrukcyjnej". Zagadnienia Eksploatacji Maszyn, 1-2/1993, pp. 125-133

5. Heinrich M., Lenkiewicz W. „Erhöhung und Auswertung des Zuverlässigkeitsniveaus von tribologischen Paarungen im Zeitraum der Anfangsnutzung eines einzelnen Objekts". Tribologie und Schmierungstechnik 3/2002, pp. 43-46

6. Altszuller H. Algorytm wynalazku. Warszawa, Omega Wiedza Powszechna, 1973

7. http://www.triz-innowacje.pl/slownik-terminologii.html

8. Altszuller H. Elementy teorii twórczości inżynierskiej. Warszawa, Wydawnictwa Naukowo-Techniczne, 1983

9. Knosala R., Boratyńska-Sala A., Jurczyk-Bunkowska M., Moczała A. Zarządzanie innowacjami. Warszawa, Polskie Wydawnictwo Ekonomiczne, 2014

10. Альтшуллер Г. Найти идею. Введение в ТРИЗ - теорию решения изобретательских задач. Москва, Альпина Паблишер, 2012

Author (co-author) to contact: Maksymilian Smolnik, smolnik@agh.edu.pl

TRIZfest 2014

A TRIZ Lens for Patent Searching

Srikanth Tadepalli[a], Vinodh Mewani[a], Anand Biswas[a]

[a]*Patents and Analytics Center of Excellence (PACE), Bangalore, 560 066, India*

Abstract

The world of patents is a representative system of technological evolution and is of interest to patent professionals to gage the state-of-art. A critical facet of this ecosystem is landscaping a scientific segment of interest, an exercise that involves identification of pertinent patents in that segment. Several trends and correlations can be derived by analyzing key patents of interest once the relevant set of references is retrieved. However, search and filtration of references that are down-selected based on keywords, their syntactical variations and keyword combinations tend to be time consuming and subject to interpretation. Further, not all word variants can truly be captured as patent law allows the applicant to be his/her own lexicographer. Modern search engines (e.g. Prosearch^{TM}) [1] also rely on semantics and learning algorithms to identify patents of interest to reduce noise in the search and maximize count of relevant records. These engines are based on heuristic models that train the algorithm to look for existence of certain keywords based on parameters like frequency of occurrence, word proximity to another phrase, occurrence of the search concept in a particular section of the patent etc. While the results produced are better than the conventional approach, there is room for statistical errors and the associated software can be cost intensive. In this paper, we propose an alternate method of TRIZ based search wherein search for patents of interest relies on TRIZ tools and methodologies that accounts for word alternatives and minimizes subjectivity in interpretation. We also demonstrate the efficacy of the process by comparing S/N ratio between the conventional approach and the TRIZ based approach.

Keywords: TRIZ, Patent Landscape, Patent Searching, S/N Ratio

1. Introduction

Patent searching is an art which requires thorough understanding of the technical subject, comprehension of specific features of interest within the subject, identification of search concepts (keywords) signifying these specific features of interest, isolation of keyword changes to account for word variations due to geography and vocabulary, and formulation of a search string representative of the search concepts. The *search strategy* is thus a combination of the search string, jurisdictions to search, timelines and possible additional use of IPC codes[1]. Further refinement is also possible by selecting different fields to search in a patent like claims, abstract or title. Quality of the search strategy is empirically measured based on the number of pertinent records retrieved from the search, representing the *signal* component of the search results (*S*), in relation to the irrelevant records generated from the search, denoting the *noise* (*N*) part.

[1] IPC Codes: International Patent Classification Codes – Codes assigned by patent offices across the globe to patents to classify them under a technology segment.

Typically, noise is fairly high due to multiple synonyms used to classify a keyword and when coupled to several such keywords with their individual synonyms, noise increases exponentially. Sifting through each record for relevance in a large dataset dominated by noise is time and effort intensive. Further, the problem becomes aggravated when certain keywords are spelled or interpreted differently in different countries. For instance, "Accumulator" in the German jurisdiction signifies a source of electro-chemical energy storage which is conventionally referred to as a cell or battery elsewhere. Likewise, "airfoil" is spelled as "aerofoil" in UK despite both defining the exact same structure. It is thus important to recognize that not just spellings but word variations in geographies need to be accounted for to ensure a robust search. It is hence highly desirable to have a search mechanism where signal to noise ratio (S/N) is high so that time investment in record filtration is not as pronounced as the conventional process. In this paper, such a technique based on TRIZ is expounded where the three main performance criteria, enumerated below, are met.

1. Number of relevant records identified in the conventional search and featuring in the TRIZ based search must be maximized.
2. Number of relevant records identified in the conventional search and not featuring in the TRIZ based search must be minimized.
3. $\left(\frac{S}{N}\right)$ ratio of the TRIZ based search must be higher than that of the conventional search.

It is important to elucidate on these performance criteria to highlight their significance. Conventional search, without any dispute, casts the widest net in terms of capturing the search space. To compare a new paradigm of searching with this well-established process requires its output to be commensurate with the traditional procedure. Any new method of search is of little interest if it does not capture applicable records like the conventional method and/or generates comparable $\left(\frac{S}{N}\right)$ ratio. The motivation in seeking a new search methodology is to reduce time and effort, which can only be obtained when $\left(\frac{S}{N}\right)$ ratio is better than the known procedure while the number of records rated as relevant is identical (or almost identical) between the two schemes. Some effort has gone into addressing each of these criteria with increased use of learning/training algorithms, pattern matching, frequency analysis of keywords, distance between search concepts, citation networks etc. that have increased the $\left(\frac{S}{N}\right)$ ratio. However, access to these tools is quite limited due to their cost ($3500.00 for a yearly subscription of Prosearch^{TM}) [1], and for manual users relying on database searching, a simple tool that is relatable and not too different from the known method would be beneficial. It is prudent at this juncture to gage prior efforts in this area to establish gaps and unmet operational needs so that a stronger case is made for the proposed alternative TRIZ based search.

2. Literature Review

A targeted background survey has been done to understand previous efforts in this area. A notable publication in the domain is from Liang et al. [2] wherein relevant patents have been down-selected based on text mining of principles and contradictions disclosed in patents. Regazonni et al. [3] discuss similar ideology in their paper with a partially automated procedure employed to identify relevant patents using structured queries. Cong et al. [4]

introduce the concept of text and meaning similarity to automatically classify and retrieve patent documents. Mehta et al. [5] attempt to do similar work by combining TRIZ and patent citations. Cascini et al. [6] correlate patents and TRIZ via computer aided analysis, and search for TRIZ contradictions using technology forecasting. Across these papers analyzed, no actual mention of search string formulation is mentioned that allows for high $\left(\frac{S}{N}\right)$ ratio, which is the motive of this paper.

3. Methodology

It is important to understand that the methodology being proposed in this paper is different from the conventional search in two aspects –

a) Fields and super-system components are included in the search.

b) In the selection of super-system components, only *functionally contributing* components are chosen *i.e*., only those super-system components which affect the functioning of the device are included in the analysis.

Both these features are corner stones of the proposed method. Elucidating, conventional search process includes elements in the search as derived from the problem statement and **does not** incorporate fields acting in the system unless *explicitly stated*. Inherent fields are rarely included even though they are contributing to the working of the device. This gap has been noticed in the searches done historically and has been thus been included in our methodology to complete the process from a *field* standpoint. Secondly, search process in the traditional mode is typically centred on the device and its features, and **does not** include effects of its interaction with the super-system, which can influence its functionality significantly. Some of these super-system components are present due to their physical proximity with the device while others are actually participating, implying that their interaction with the device has a bearing on the device itself. Therefore, these partaking components albeit their super-system ranking still need to be included in the search for the process to be complete from a *substance* perspective. Thus, we refine the conventional search process by *appending* components of field from the system and substances from the super-system provided the substances are interacting functionally. In formulating the TRIZ based search string, a simple algorithm is followed –

i) Create a problem statement for the search.

ii) Build a Su-F model for the problem statement.

iii) Include all system substances and fields in the search string.

iv) Incorporate super-system substances and fields if they are functionally relevant.

v) Add classifying terms if the Su-F suggests so.

Both modifications introduced in the earlier text and the developed algorithm is explicated in the case studies provided next.

4. Case Studies

Continuing with our discussion on the modified search process, a couple of case studies are presented in this section to buttress the argument about improvement of search results. The first case study shown is that of a briefcase with a sensor. A sensored baggage allows ease in tracking for both travellers and airline staff. A traveller is intimated about the arrival of his/her luggage on the carousel while the airlines can use such information to ensure no loss or misdirection of cargo. Such intelligent baggage is thus required and justified. Putting the algorithm to test –

4.1 Case Study 1

i) Problem Statement: Find patents published between 1/1/2014 and 1/31/2014 that disclose briefcases with sensors.

Conventional search: (Briefcase + synonyms) and (sensors + synonyms) and Timeline and relevant IPC Codes

TRIZ Based Search:

ii) Su-field model:

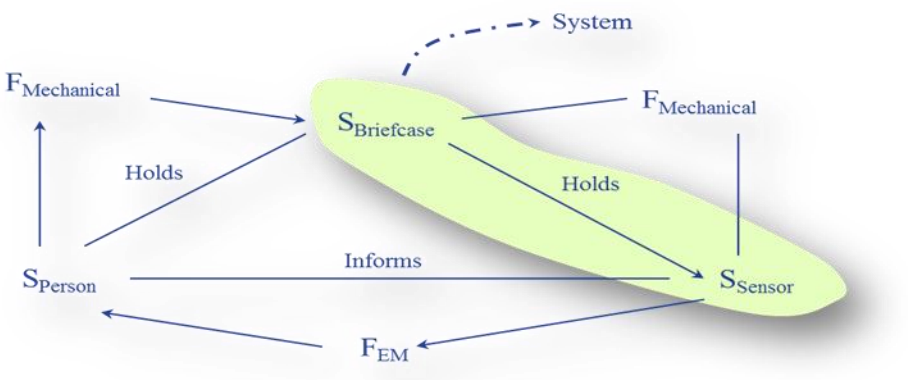


Figure 1. Su-F model for briefcase with sensor

iii) Modified Search String: (briefcase + synonyms) and (sensors + synonyms) and (mechanical + synonyms) and (electromagnetic + synonyms) and Timeline and relevant IPC codes

iv) Enhanced Search String: (briefcase + synonyms) and (sensors + synonyms) and (mechanical + synonyms) and (electromagnetic + synonyms) and (hand + synonyms) and Timeline and relevant IPC codes

v) Classifications: Since the Su-F is not analyzed, there are no further terms to include.

Table 1. Comparison of search results

Performance criteria	**Results**	**Conventional search**	**TRIZ based search**	**Are the results common?**
Number of relevant records identified	US8531290B2 US8456303B1 US8397310B2 US20130320076A1 WO2013187387A1	9	9	Yes
Number of			0	

relevant records missing	AU2010244976B2 KR1280655B1 CN203314322U CN203168296U			
Overall results		396	281	
Noise		387	272	
Ratio		2.33%	3.11%	

Notice from the table above that all three criteria have been met but $\left(\frac{S}{N}\right)$ ratio has only marginally improved. This small increase is attributed to the missing classifications from step 5 that add additional benefit in terms of function identification. However, the basic framework of the methodology is illustrated definitively. The next example address the issue of increasing $\left(\frac{S}{N}\right)$ ratio significantly by analyzing interplaying functions so as to generate the classification keywords.

4.2 Case Study 2

i) Problem Statement: Find patents published between 1/1/2014 and 1/31/2014 that disclose coffee cups with handles that allow better holding while containing hot coffee.

Conventional search: (coffee + synonyms) and (cup + synonyms) and (hold + synonyms) and (hot + synonyms) and (handle + synonyms) and Timeline and relevant IPC Codes

TRIZ Based Search:

ii) Su-field model:

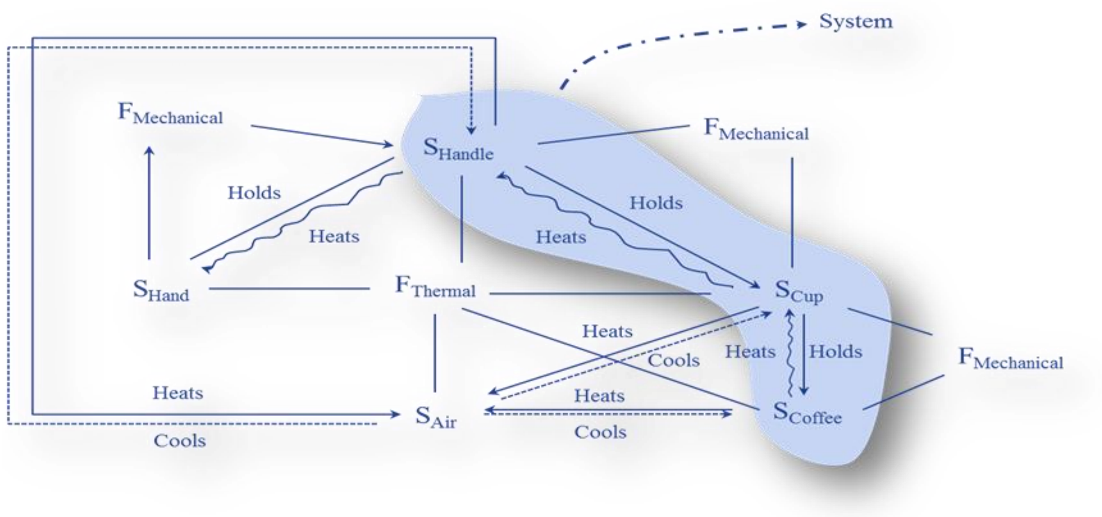


Figure 2. Su-F model for coffee cup with handle

iii) Modified Search String: (coffee + synonyms) and (cup + synonyms) and (hold + synonyms) and (handle + synonyms) and (thermal + synonyms) and (mechanical + synonyms) and Timeline and relevant IPC Codes

iv) Enhanced Search String: (coffee + synonyms) and (cup + synonyms) and (hold + synonyms) and (handle + synonyms) and (thermal + synonyms) and (air + synonyms) and (mechanical + synonyms) and Timeline and relevant IPC Codes

Notice that "hand" is not incorporated into the search string despite being a super-system component as it does not contribute functionally (ease of holding during high temperature) to the system. Further, analyzing the Su-F model, notice that there are three harmful functions between the hand-handle, cup-handle and coffee-cup. The recommended set of standard inventive solutions offers four possibilities for destroying a harmful Su-F.

Option 1: Add a negating field.

The only possible fields that can be added in this context are a vibrating or a cooling field, which can be achieved respectively by the hand oscillating the cup risking spillage of hot coffee or by blowing air. Both these variants are not feasible for this problem as they involve human intervention.

Option 2: Add a substance from the super-system.

This option would entail incorporating a glove or protective hand cover, which would solve the problem but does not necessarily lead to an invention in the cup or its handle.

Option 3: Add a sacrificial substance.

A coating of some thermal resistance can be added but in due course of time, the coating will disintegrate or wear rendering the cup incapable of further use, and hence is a solution of a temporary kind.

Option 4: Add a substance that is a modification of either participating substances in the Su-F. Across the Su-F, discarding the hand and coffee, as no modification can be made to their properties, leaves the cup and handle as candidates for modification, in their shape or material.

v) Classifications: Since the Su-F is analyzed, the search string is further refined by adding terms reflecting modification of shape and/or material. (coffee + synonyms) and (cup + synonyms) and (hold + synonyms) and (handle + synonyms) and (thermal + synonyms) and (air + synonyms) and (mechanical + synonyms) and (modify + synonyms) and (shape + synonyms) and (material + synonyms) and Timeline and relevant IPC Codes

Table 2. Comparison of search results

Performance criteria	**Results**	**Conventional search**	**TRIZ based search**	**Are the results common?**
Number of relevant records identified	US8622235B2 US8622232B2 US8622208B2 US20140015164A1 US20140008374A1 EP2280885B1 EP2408682B1 EP2688731A1 WO2014008595A1 AU2012271047A1 AU2013204654A1 JP03188316U KR2014000391A	13	12	Yes
Number of relevant records missing			1	
Overall results		123	79	
Noise		110	67	
Ratio		11.82%	17.91%	

In this case, $\left(\frac{S}{N}\right)$ ratio has improved dramatically but 1 relevant record has not been captured by TRIZ based search. On further investigation, the missing record has been identified to be the Korean disclosure (KR2014000391A), which has not been found by TRIZ based search due to inconsistency in translation to English. This limitation has been accepted as learning from the current exercise to facilitate future developments which should include possible language translation issues. Comparing the results between the two examples,

Table 3. Comparison of performance metrics

	Are all results in the signal list of the conventional search featuring in the TRIZ based search?	Are there any results in signal list of the conventional search that are NOT featuring in the TRIZ based search?	Improvement in S/N ratio
Problem 1	100%	0	0.98%
Problem 2	92%	1	6.09%

5. Conclusions

Summarizing our effort, we have elaborated on an improved process of TRIZ based patent searching such that relevance is not compromised while reducing time required in isolating such relevant records. Further, we have also demonstrated quantitatively, how a simple extension of the problem statement to include fields and their interactions with substances substantially augments the search process. Finally, additional benefit realized in analyzing the substance-field model to address harmful functions and insights TRIZ offers in dealing with such situations is highlighted in terms of formulation of a robust search string, which enhances the performance metrics further. Note however that the new search process only complements and does not replace the traditional search technique. It is useful when time and convenience is of interest and should be viewed only as a sub-set of the conventional approach. Some knowledge of TRIZ is pre-supposed but the benefit achieved (recurrent) far outweighs the cost incurred in obtaining such skill in TRIZ.

Acknowledgements

The authors gratefully acknowledge help and assistance provided by PACE leadership in GE Bangalore for their continued support of our TRIZ initiatives and publication activities.

References

1. http://www.pantrosip.com/solutions/patent-search

2. Liang Y., Tan, R., Ma, J. “Patent analysis with text mining for TRIZ”, 4th IEEE International Conference on Management of Innovation and Technology, 2008

3. Regazzoni D., Nani, R. “TRIZ-Based Patent Investigation by Evaluating Inventiveness”, Computer-Aided Innovation (CAI) - The International Federation for Information Processing Volume 277, 2008, pp 247-258.

4. Cong, H., Tong, L.H. “Grouping of TRIZ Inventive Principles to facilitate automatic patent classification”, Expert Systems with Applications: An International Journal archive, Volume 34 Issue 1, January, 2008, Pages 788-795.

5. Mehta, S.B., Bhushan, N., Mishra, P. “Searching for relevant patents using TRIZ and Patent Citation Analysis – a Case Study”.

6. Cascini, G., Russo, D. “Computer-aided analysis of patents and search for TRIZ contradictions”, International Journal of Product Development.

Author (co-author) to contact: Srikanth Tadepalli, srikanth.tadepalli@ge.com

TRIZfest 2014

Algorithm for Selecting TRIZ Tools

Vladimir Petrov

Raanana, 6/4 Klauzner St. 43367, Israel

Abstract

TRIZ includes a number of tools. It can be difficult for a beginner solver to properly select a specific TRIZ tool, or a group of tools and the sequence of their use during a project.

This paper presents the attempt to show consistency in using different tools for some types of problems and a sequential process which was developed as an algorithm shown in the flowchart in the paper.

Keywords: TRIZ tools, types of problem, types of innovation projects, algorithm for selecting tools

1. Publication review

Application of various tools of TRIZ and an order of their use were first proposed by G. Altshuller in different modifications of ARIZ [1-7]. Each new version of ARIZ included new tools of TRIZ [8].

Software packages TechOptimizer [9] and IWB [10] provide an option of selecting and using different TRIZ tools. A company Gen3 Partners developed a roadmap which presents a sequence of application of different TRIZ tools.

The author of the paper developed a method which combines different tools of TRIZ [11-13]. The method presents a number of sequences in which the TRIZ tools can be used for the analysis of existing systems, synthesis of new systems, forecast of systems evolution and solving typical inventive problems.

All these works make the use of TRIZ by a beginner easier. At the moment however there is a lack of a unified vision of what sequences should be used to solve different types of tasks and performing different projects.

This paper presents an attempt to produce the next step towards developing such the vision. The paper will demonstrate a possibility of using specific TRIZ tools and their sequences for specific types of projects.

2. Functions and Structure of TRIZ

Functions and structure of TRIZ are presented in [14]. Let us introduce them in a more extended form.

Functions of TRIZ

Among the main functions of TRIZ are:

1.1 A new system synthesis.

a. Synthesis of a system of a new generation.

b. Synthesis of a radically new system.

1.2. Improvement of an existing system.

a. Elimination of disadvantages.

b. Functionality improvement.

c. Costs reduction.

1.3. The use of a system within a new context.

a. Extending the line of use of the existing system.

b. Find a new application area for the existing system.

4. Search for problems.

5. Formulation of Intellectual Property (IP) Strategy.

6. Development of creative skills.

a. Development of inventive thinking.

b. Development of creative personality.

c. Development of creative communities.

Structure of TRIZ

Main components of TRIZ:

1. Laws of Evolution.

1.1. Laws of Engineering Systems Development.

1.2. Laws of evolution of needs.

1.3. Laws of functions change.

2. ARIZ.

3. Substance-Field Analysis.

4. TRIZ Knowledge Base:

4.1. Standards.

4.2. Effects.

4.3. Principles.

4.4. Recourses.

5. Anticipatory Failure Determination.

6. System Analysis and Synthesis.

6.1. System and Function Analysis.

6.2. Analysis and synthesis of needs.

6.3. System Synthesis.

7. Cause and Effect Analysis.

8. Value Analysis.

9. Method of generating IP strategy.

10. Methods of developing creative thinking.

10.1. System thinking.

10.2. Evolution thinking.

10.3. Contradiction-based thinking.

10.4. Resource thinking.

10.5. Modelling.

10.6. Development of creative imagination.

11. Theory of Creative Personality Development.

12. Theory of Creative Community Development.

All sections of TRIZ can be roughly divided to two parts: methods of solving problems and methods of developing creative skills. Items 1-9 belong to the category of methods of solving problems while items 10-12 belong to the category of methods of developing creative skills. A structure of TRIZ according to this classification is presented in Fig. 1.

Problem Solving	**Developing Creative Skills**
Laws of Systems Evolution	
ARIZ	**Methods of developing creative thinking**
Substance-Field Analysis	
TRIZ Knowledge Base – ***Standards.*** – ***Effects.*** – ***System of Principles.*** – ***Resoutces.***	**Theory of developing a creative personality**
Anticipatory Failure Determination	
System Analysis and Synthesis – ***System and Function Analysis.*** – ***Analysis and Synthesis of Needs.*** – ***System Synthesis.***	**Theory of developing a creative community**
Cause and Effect Analysis	
Value Analysis	
IP Strategy	

Figure 1. Structure of TRIZ

1.3. The Use of Tools of TRIZ

Each tool of TRIZ can be used for each function of TRIZ. Some tools can be used for several functions. The author developed a table of matching specific TRIZ tools against specific functions of TRIZ. A fragment of such table in shown in Table 1.

Table 1. Function and structure of TRIZ

Function		Structure															
								Knowledge Base							Methods of creative development		
									Effects								
		Laws of developing TS	ARIZ	Substance-Field Analysis	Anticipatory Failure Determination	System analysis & synthesis	Function analysis & synthesis	Standards	Physical	Chemical	Biological	Mathematical	Inventive Principles	Resources	Imagination	Personality	Team
1	System Forecasting	1	-	2	3	1	3	2	-	-	-	-	-	-	-	-	-
2	New system synthesis	1		2	2	1	1	2	2	2	2	2		2	3	-	-
3	Existing system improvement	1	1	1		1	1	1	1	1	1	1	1	1	3	-	-
4	Search for problems	1	-	2	1	1	-	1	3	3	3	3	4	3	4	-	-
5	Problem selection	1	1	-	-	1	1	2	-	-	-	-	-	-	-	-	-
6	Problem solving	2	1	2	1	2	1	1	2	2	2	2	2	2	3	-	-
7	Solution evaluation	1	2	2	2	2	2	1	-	-	-	-	-	-	-	-	-
8	Development of creative imagination	2	-	-	3	2	-	-	-	-	-	-	3	2	1	-	-
9	Development of a creative personality	-	-	-	-	2	-	-	-	-	-	-	-	-	-	1	-
10	Development of a creative community	-	-	-	3	2	-	-	-	-	-	-	-	-	-	-	1

Notes: In the table, numbers represent the priority of the application, which approximately corresponds to the degree of importance of a tool for the function given. The symbol "**-**" means that a tool given is not applicable to fulfill a function.

2. Sequence of Applying the TRIZ Tools

As a rule, fulfilment of the abovementioned functions and execution of innovative projects requires using several tools of TRIZ and the order of applying the tools is of importance. Each function can demand its own sequence. The author developed specific recommendations. We will present some of them below.

2.1. The use of a system within a new context

One of the types of innovative projects is to find a new application area for a system which already exists. To reach this goal the author developed a method in 1974 which was published in [15]. The method is based on the maximization of the use of resources available in the system.

First, all resources which belong to the system are extracted and described. The next step is to discover how these resources can be used.

The following types of resources are used:

1. Functions.
2. Components.

8. Field.
9. Flows (of substance, energy and information).

3. Links between the components.
4. Shape.
5. Energy.
6. Information.
7. Substance.
10. Space.
11. Time.
12. Processes.
13. Parameters.
14. System resources.

The resources can belong to *system*, *subsystems*, supersystem and environment. They can be used as ready to use or in a modified form.

The sequence of the use of discovered properties within a new context can be the following:

1. The use of the system as a whole.
   1.1. Application of main properties, functions, actions within a new context as main properties, functions, and actions.
   1.2. Application of additional properties, functions, actions as main properties, functions, and actions.
   1.3. The use of neutral or harmful properties, functions, actions as useful properties, functions, and actions.
   1.4. The use of properties, functions, actions which are reverse to the presented ones.
2. The use of subsystems is similar to point 1.
3. The use of substances and fields of subsystems.
   3.1. The use of substances and fields which are principal for the system and its subsystems.
   3.2. The use of substances and fields which are auxiliary for a system given as main substances and fields.
   3.3. The use of neutral substances and fields which are auxiliary for a system given as useful substances and fields.
4. The use of a structure of a system at microlevel.
   4.1. The use of main properties of the structure at microlevel: molecules, atoms, elementary particles, etc.
   4.2. The use of auxiliary properties of the structure at microlevel.
   4.3. The use of neutral properties of the structure at microlevel as useful.
   4.4. The use of harmful properties of the structure at microlevel as useful.

To search for new application areas on the basis of the extracted resources, one can use a brainstorming process with involvement of specialists from diverse domains. In addition, to discover new applications one can use any functional classification available, for example, the classification provided by the US Patent and Trademark Office. There is also a set of recommendations on how to use separate properties. In the future, the roadmap of the use of properties and functions should be developed.

2.2. Algorithm of using the tools of TRIZ to synthesize new systems and improve existing systems

The algorithms of using the tools of TRIZ for a function of solving problems and producing a forecast are presented in [13].

A simplified sequence of using the tools of TRIZ for the function of synthesis of new systems and improvement of existing systems is shown in Fig. 2. The steps in the algorithm are as follows:

1. Improvement of an existing system.

1.1. Elimination of disadvantages and drawbacks.

1.1.1. If a problem is known then the substance-field analysis or elimination of contradictions have to be used.

1.1.1.1. Substance-field analysis or elimination of contradictions.

1.1.1.2. Substance-field analysis.

1.1.1.2.1. If a solution has been obtained with the substance-field analysis, the process is finished.

1.1.1.2.2. If a solution has not been obtained, the TRIZ Knowledge Base is used.

1.1.1.3. Elimination of contradictions.

1.1.1.3.1. If a type of a contradiction is known then the TRIZ Knowledge Base us used.

1.1.1.3.2. If a type of a contradiction is not known then ARIZ is used.

1.1.2. If a problem is not known then one should use:

1.1.2.1. System-oriented analysis. If it is not enough then a cause-effect analysis, anticipatory failure analysis and value analysis can be used.

1.1.2.2. If a solution has been obtained with the substance-field analysis, the process is finished.

1.1.2.3. If a solution has not been obtained then go to step 1.1.1.3.

2. Synthesis of a new system

2.1. Synthesis of a system of a new generation.

As a rule, changes primarily occur at the system level while the system’s main principle tends to change less often. In this case the method of forecast [18-21, 24] and the laws of engineering systems development have to be used [22-24].

2.2. Synthesis of a radically new system.

2.2.1. The use of system-oriented analysis from [12] and [13].

2.2.1.1. *Development of a model of needs*. It requires the use of a method of discovery of hidden needs and forecast of future needs [16].

2.2.1.2. Development of Function Model [12].

2.2.1.3. Development of a model of principles of action [17].

2.2.1.4. *Development of a system model*. In this case the method of forecast [18-21, 24] and the laws of engineering systems development have to be used [22-24].

2.2.2. Forecast verification.

2.2.3. Improving a newly invented system – go to step 1.

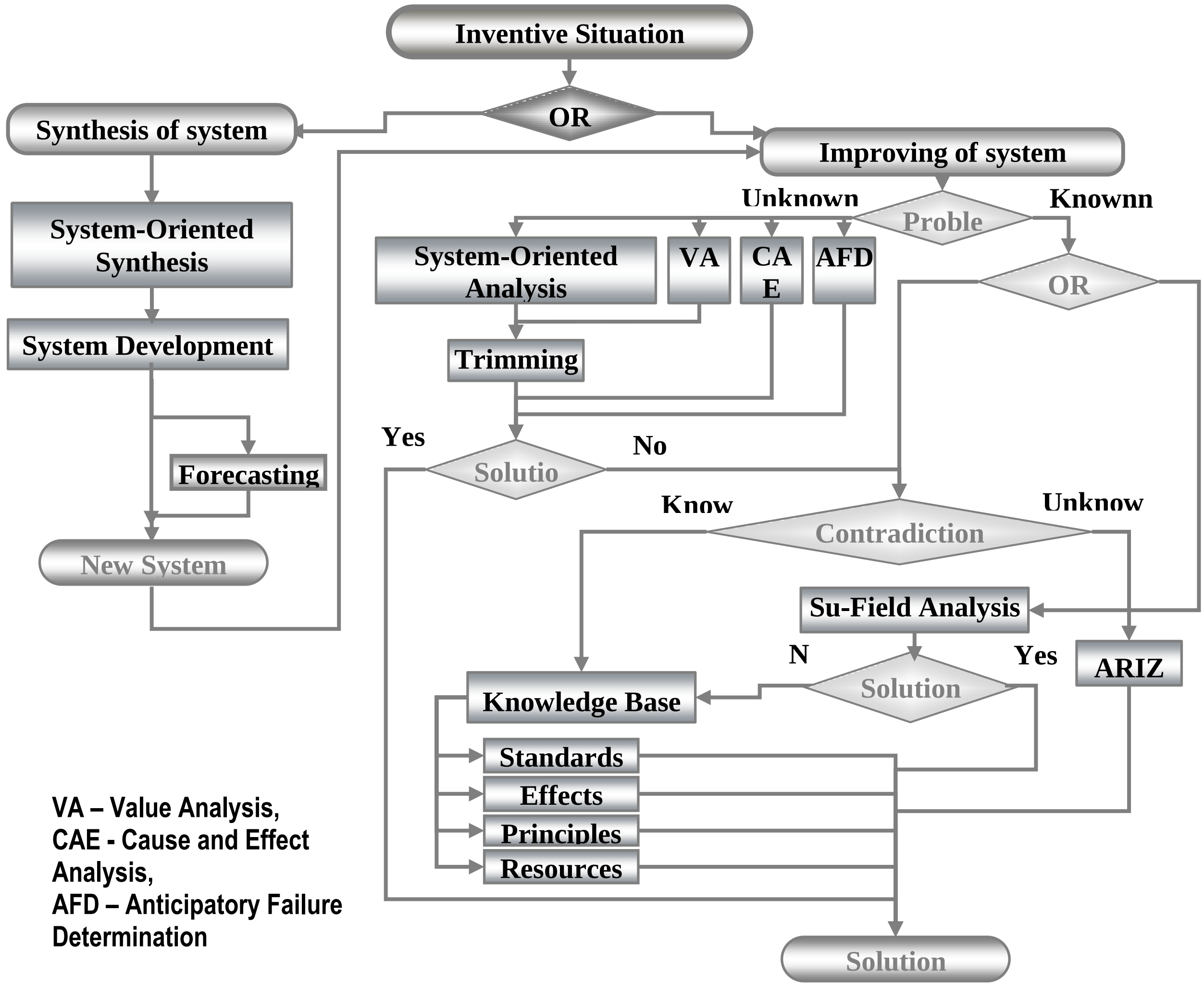


Figure 2. Algorithm for selecting TRIZ tools

The paper presented the main functions and a structure of TRIZ as well as demonstrated which tools of TRIZ have to be used to most effectively fulfil the main functions of TRIZ. It also presented the sequences of the use of the TRIZ tools to fulfil some functions of TRIZ.

References

1. Altshuller G.S. Algorithm of Invention. Moscowskiy Rabochiy 1969. 89-93. (in Russian)

2. Altshuller G.S. Algorithm of Invention. Moscowskiy Rabochiy 1973. 111-118. (in Russian)

3. Altshuller G.S. Theory and Practice of Solving Inventive Problems. Gorkiy, 1976. 191-196. (in Russian)

4. Altshuller G.S. Creativity as an Exact Science. Sovetskoe Radio, 1979. 154-159. (in Russian)

5 Altshuller G.S. Algorithm of Solving Inventive Problems ARIZ-85B. Sverdlovsk, VIPK Mincvetmet USSR. 1985. (in Russian)

6. Altshuller G.S. ARIZ Means Victory. Algorithm of Solving Inventive Problems ARIZ-85C.In: Rules of the Game without Rules (Selyutski A., ed.), Petrozavodsk, 1989. 11-50. (in Russian)

7. Altshuller G.S., Zlotin B.L., Zusman A.V., and Filatov V.I. Kishinev, Karte Moldavenyaske, 1989, 381p. (in Russian).

8. Petrov V. History of Developing Algorithm of Solving Inventive Problems ARIZ. Second edition. Tel Aviv, 2008 – 196p. Electronic Library of TRIZ Developers Summit, Issue 1, July 2008. http://triz-summit.ru/ru/section.php?docId=3987 (in Russian)

9. TechOptimizer. Software Invention Machine Corp.

10. IWB. Software Ideation International Inc.

11. GEN3 Innovation Discipline – Basic Course Training Guide. GEN3 Partners, Inc., 2006, P. 4.

12. Petrov V. Technology of Innovations. Tel Aviv, 2007. 93p. http://www.triz-summit.ru/ru/section.php?docId=4732 (in Russian)

13. Petrov V. System of Unified Models – Development of Tools for Solving Inventive Problems. Conference Proceedings. Library of TRIZ Developers Summit Issue 2. St. Petersburg, SPGPU. 2008. pp 102-111. http://www.triz-summit.ru/ru/section.php?docId=3896 и http://www.triz-summit.ru/ru/section.php?docId=472 (in Russian)

14. Petrov V. THE STRUCTURE AND FUNCTIONS OF TRIZ. ETRIA World Conference – TRIZ Future 2003. November 12-14, 2003 http://www.triz-journal.com/archives/2003/09/d/04b.pdf. http://www.triz-summit.ru/en/section.php?docId=4147

15. Petrov V. Basis of the Theory of Applicability. Seminar Materials. LDNTP, 1978. (in Russian)

16. Vladimir Petrov. Laws of Development of Needs. – TRIZ Futures 2005. 5th ETRIA Conference. November 16 to 18, 2005. Graz, Austria. 151-174 conference. – The TRIZ Journal. http://www.triz-journal.com/archives/2006/03/02.pdf

17. Petrov V.M. Defining the Operation Principle of the Engineering System. /Operation Principles of System / Collection of Scientific Papers, TRIZ Developers Summit Library. Volume 4. Saint Petersburg, 2011. P. 74, 87-108.

18. Petrov V. Forecast of Systems Evolution. Tel Aviv, 2002. http://www.trizland.ru/trizba/pdf-books/zrts-19-prognoz.pdf (in Russian)

19. Petrov V. Technique of Forecast. Methods of Forecast on the Basis of TRIZ. Conference Proceedings. Library of TRIZ Developers Summit Issue 3. St. Petersburg, 2010. 19-25. (in Russian)

20. Petrov V.M. System of Laws of Technology Development as a Tool of Forecast. Conference Proceedings. Library of TRIZ Developers Summit Issue 3. St. Petersburg, 2010. 26-41. (in Russian)

21. Petrov V.M. Forecast of Evolution of Technical Systems. Methods of Forecast based on TRIZ. Conference Proceedings. Library of TRIZ Developers Summit Issue 3. St. Petersburg, 2010. pp. 204-221. (in Russian)

22. Vladimir Petrov. The Laws of System Evolution. TRIZ Futures 2001. 1st ETRIA Conference 2001. – The TRIZ Journal http://www.triz-journal.com/archives/2002/03/b/index.htm. http://www.triz-summit.ru/en/section.php?docId=4147

23. Petrov V. The laws of system development. In: Papers of TRIZ-FEST-2011 Conference Collection of Scientific Papers, MATRIZ, Saint Petersburg, 2011. – P. 65, 201-206.

24. V. Petrov. The Laws of System Evolution. Berlin: TriS Europe GmbH, 646 pages, published in Russian. (INNOVATOR (06) 01/2013, ISSN 1866-4180. Петров В. Законы развития систем. Монография. Тель-Авив, 2013 – 646 с.)

Author (co-author) to contact: Vladimir Petrov, vladpetr@013net.net

TRIZfest 2014

Alternative Ways to Formulate or Model an Individual Engineering Contradictions for the Sake of its More "Natural" Solving

Stéphane Savelli

MP Solving, Brussels, 1000, Belgium

Abstract

The solving of an individual engineering contradiction has been explored. A 3D representation of a pair of engineering contradictions (EC1, EC2) and the groups of solutions corresponding to their individual solving (GS1 and GS2) is proposed. Besides, the concept of equivalent physical contradiction ePC (to a pair of engineering contradictions) is introduced. It is shown that GS1 and GS2 correspond exactly to the group of solutions coming from the resolution of ePC by the means of satisfaction. A cause-and-effect chain framework allows defining two alternative solving approaches for an individual engineering contradiction. These two alternative methods are combined within a single algorithm, which allows a more direct and natural way to solve an individual engineering contradiction than the Altshuller matrix. Beyond that algorithm, the combination of this algorithm in parallel with the physical contradiction resolution method by the means of separation and bypass allows the proposal of a complete alternative to the Altshuller matrix. This complete alternative method overcomes some limits of the Altshuller matrix and proposes a more direct and natural way to solve any pair of engineering contradictions, or equivalently, any physical contradiction. This novel approach is universal because it is field-independent.

Keywords: individual engineering contradiction, equivalent physical contradiction, cause-and-effect chain, Altshuller matrix, algorithm, satisfaction of the contradiction.

1. The Altshuller Matrix: its advantages and limits

1.1. Advantages

One of the best known methods to solve an identified inventive problem is – if possible - to select and formulate a specific pair of engineering contradictions describing this problem, to use the Altshuller matrix to determine the recommended inventive principles which are potentially inspiring for its resolution, and finally to propose inventive solutions that are concrete enough and adapted to the specific context of the problem at hand.

Accordingly the Altshuller matrix is an interesting analytical and solving tool from the TRIZ toolbox, for different reasons. First it can provide a good introduction to TRIZ and to the concept of contradiction, and from a more practical point of view, beginners can solve successfully some first educative or real, inventive problems, and consequently be motivated to keep up learning TRIZ. Second, this tool illustrates very well the general approach for applying TRIZ, consisting of four consecutive steps: specific problem $\Rightarrow$ model of the problem $\Rightarrow$ model(s) of solution(s) $\Rightarrow$ specific solution(s). Third, it is a historical tool developed by Altshuller himself, and is still strongly in use among TRIZ practitioners and professionals.

1.2. Limits

However the Altshuller matrix may sometimes show some limits. Its use is not always straightforward. Actually practitioners may sometimes feel uncertainty while attempting to determine which couple of parameters among the 39x38 (or more in modern versions of the matrix [1]) that the matrix proposes matches with the pair of engineering contradictions at hand. Sometimes several couples of parameters may seem the right ones to choose. As a result, practitioners may lack confidence in the recommended inventive principles proposed by the matrix, possibly because they may have too many inventive principles to be inspired from. At the extreme limit, a sequential review of all 40 inventive principles might appear as a valuable option, therefore avoiding the need to complete use of the Altshuller matrix, but making the work very tedious. Furthermore, in some instances, despite their detailed recommendations, the inventive principles might seem too abstract to really help practitioners to find one or several concrete, inventive solutions.

1.3. Main objective

The main objective of the present paper is to explore some alternative ways to solve an engineering contradiction without using the Altshuller matrix. As a starting basis for this exploration, a graphical representation of a pair of engineering contradictions will first be presented.

2. Graphical representation of a pair of engineering contradictions and the groups of inventive solutions corresponding to their respective individual resolutions

2.1. Graphical representation of a pair of engineering contradictions

Without any loss of generality, any pair of engineering contradictions (EC1, EC2) can be expressed as follows:

EC1: If P is low, then F1 is high, but F2 is low

and

EC2: If P is high, then F2 is high, but F1 is low

Here P is a variable parameter, and (F1, F2) is a couple of characteristics or features that depend on P. Unambiguously the wished values of F1 and F2 are both high (resp. designated F1 high and F2 high), and by definition they seem impossible to reach together. One designates as IP the corresponding inventive problem.

The pair (EC1, EC2) can be represented graphically in a 3D-space with axis coordinates (P, F2, F1). This universal graphical representation of a pair of engineering contradictions (see Fig. 1) is qualitative. EC1 and EC2 are single points in this 3D space and support a compromise situation that can be represented without any loss of generality by a compromise curve C. For illustrative purposes, Figure 1 shows a continuous compromise curve C (in some instances it could be discrete). In this 3D graphical representation one can draw a straight line of particular interest, whose equation is:

(F = F1 high; F2 = F2 high) (1)

On purpose, this line is called the Wished Result (WR) line, because the Wished Result should not be confused with the Ideal Final Result, whose definition should be clarified case by case and can be manifold, whereas WR has a universal nature. The Wished Result line is a line if P values are continuous, because by definition whatever its P- value, any point of this line potentially corresponds to the resolution of the considered IP.

2.2. Graphical representation of a group of solutions corresponding to the solving of an individual engineering contradiction

On the WR line, one defines two particular points of interest: GS1 and GS2 (GS refers to "group of solutions"). GS1 is defined as the group of all the inventive solutions to EC1 considered individually as a single inventive problem, i.e. without considering the existence of EC2. GS1 has consequently a value of P which is P low. Symmetrically one defines GS2, whose value of P is P high. The dotted arrow joining EC1 and GS1 (respectively EC2 and GS2) symbolizes the necessary thinking path corresponding to the resolution of EC1 considered individually (resp. EC2 considered individually).

This graphical representation is proposed as a support for the development of the present article. But beside the main objective of this article, it can be used as a graphical framework for educative purposes, namely to more deeply understand the natures of a pair of engineering contradictions and their possible inventive solutions.

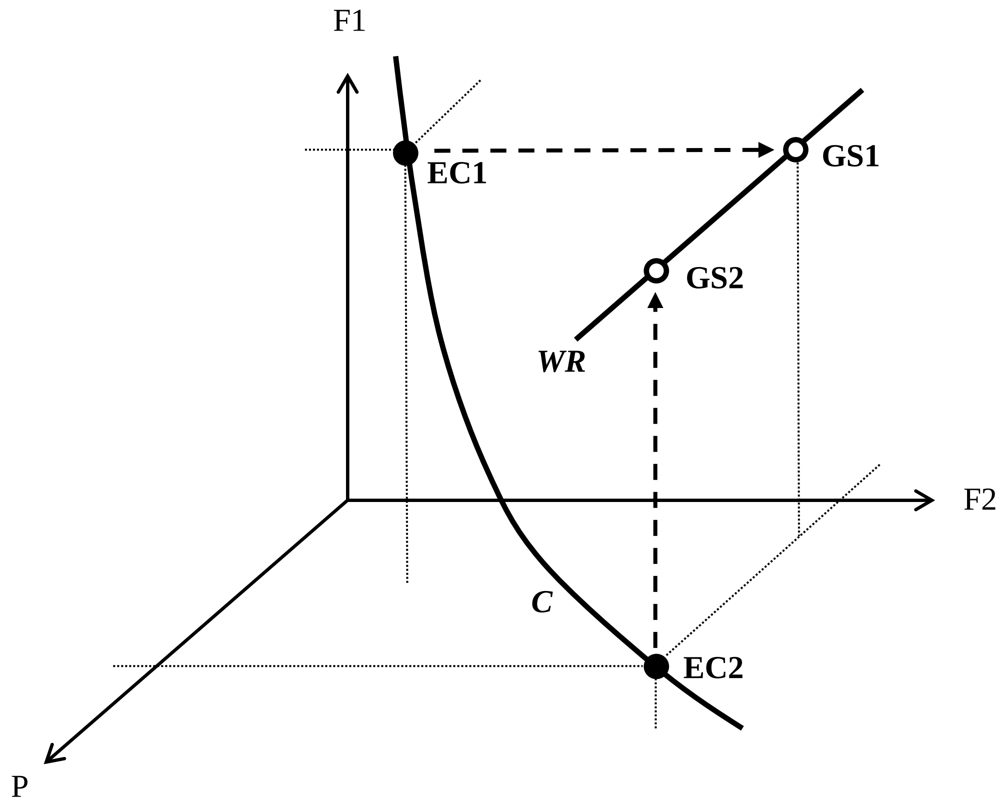


Fig. 1: 3D representation of a pair of engineering contradictions (EC1, EC2) as single points in space (P, F2, F1); WR designates the Wished Result line; GS1 (resp. GS2) represents the group of all inventive solutions to EC1 (resp. EC2) considered individually

3. The concept of equivalent physical contradiction

If one tries to solve the pair of engineering contradictions (EC1, EC2), it seems obvious that the value of P must be P low so as to obtain F1 high, and similarly the value of P must be high so as to obtain F2 high. This is exactly the structure of a physical contradiction. A lot of TRIZ specialists are aware of such a conclusion, although it seems to have been never published by G. Altshuller [2]. This physical contradiction will be called equivalent and designated as ePC. It is the same as the pseudo-fundamental contradiction [3] [4].

Let us now consider any physical contradiction PC'. Without loss of generality, it can be defined as follows:

PC': P' must be low so that F1' is high, and P' must be high so that F2' is high

Solving the physical contradiction PC' means solving the following pair of engineering contradictions (EC1', EC2') (with the same assumptions as for the above pair (EC1, EC2)):

EC1': If P' is low, then F1' is high but F2' is low

and

EC2': If P' is high, then F2' is high, but F1' is low

In EC1', F2' is necessarily low, otherwise there would be no inventive problem to solve. Similarly in EC2', F1' is necessarily low. Consequently one can state that for every pair of engineering contradictions (EC1, EC2) there is a unique equivalent physical contradiction ePC for which the resolution of (EC1, EC2) and the resolution of PC lead to the same inventive solutions. Symmetrically one can define for each physical contradiction PC' its unique equivalent pair of engineering contradictions (eEC1', eEC2').

From these logical considerations, it is recognized that a pair of engineering contradictions and a physical contradiction are finally two faces of the same coin. Only their formulation is different: a pair of engineering contradictions defines how an initial, current, non-wished situation is in reality, whereas a physical contradiction describes the necessary condition that results from the theoretical resolution of this initial situation.

4. Some equivalent groups of solutions for a pair of engineering contradictions and its equivalent physical contradiction

It can be easily expected that if a pair of engineering contradictions (EC1, EC2) has an equivalent physical contradiction ePC, there may be some equivalent groups of solutions.

For any physical contradiction PC, one can say that all its solutions must belong to one of the following groups of solutions:

1. Sa(PC), group of inventive solutions of PC resulting from the satisfaction of the contradiction;
2. Se (PC), group of inventive solutions of PC resulting from the separation of the contradictory requirements;
3. By (PC), group of inventive solutions of PC resulting from the bypass of the contradiction.

From §3 and §4, and from the former definitions of groups of solutions, it can be postulated that:

GS1(EC1) $\cup$ GS2(EC2) = Sa(ePC) (2).

This formula means the following: considering any pair of engineering contradictions (EC1, EC2), the two groups of inventive solutions coming from the resolution of the individual engineering contradictions, GS1 and GS2, as represented in Figure 1, correspond exactly to the inventive solutions coming from the equivalent physical contradiction ePC, the resolution being performed by means of satisfaction of the contradiction.

In order to prove this postulate, let us first recognize that according the definition of an equivalent physical contradiction:

GS1(EC1) $\cup$ GS2(EC2) $\cup$ all other inventive solutions of (EC1, EC2) = Sa(ePC) $\cup$ Se(ePC) $\cup$ By(ePC) (3).

Any solution of Se(ePC) encapsulates necessarily, by definition, the two possible values of P, P low and P high, either by separating these contradictory values in time, space, relation or system level. By definition too, this cannot be the case of any solution of GS1 (resp. GS2) which corresponds to a single value of P, namely P low (resp. P high). Therefore it is clear that:

(GS1(EC1) $\cup$ GS2(EC2)) $\cap$ Se(ePC) = $\varnothing$ (4)

Furthermore, by the mere definition of the bypass of the contradiction (new conditions are found where the existence of the physical contradiction has no meaning any more), the solutions of GS1 and GS2 and the solutions of By(ePC) must have a different nature. Therefore it can be stated that:

(GS1(EC1) $\cup$ GS2(EC2)) $\cap$ By(ePC) = $\varnothing$ (5)

The proof of the postulate follows from equations (3), (4) and (5).

Note that from (2) and (3) follows:

All other inventive solutions of (EC1, EC2) = Se(ePC) $\cup$ By(ePC) (6).

5. Causal approach to an individual engineering contradiction

5.1. Theoretical development of two new solving paths for an individual engineering contradiction

Without any loss of generality, let us consider EC1 as an individual engineering contradiction. It is possible to write EC1 as a cause-and-effect chain:

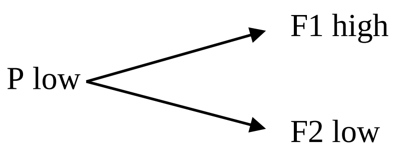


Fig. 2: Individual engineering contradiction EC1 represented as a cause-and-effect chain

In this new perspective, to solve EC1 individually means two parallel things:

1. The causal link between P low and F1 high must be maintained
2. The causal link between P low and F2 low must be modified so that P low causes F2 high

These considerations, taken together with the considerations of §2, help formulating EC1, so that it can be solved individually:

How to obtain F2 high, while maintaining P low? : Φ

Actually maintaining P low ensures that the value of F1 remains high. It can be observed from this formulation, which represents any individual engineering contradiction, **the very conflict is finally between P low and F2 high**. On the contrary, if one considers any pair of engineering contradictions like (EC1, EC2), the conflict is between F1 and F2. This change of perspective allows two possible solving approaches for EC1 considered individually:

1. A first solving approach where EC1 is solved directly, naturally, with nothing more than the mere formulation Φ (it is believed that a lot of TRIZ specialists already proceed so, possibly subconsciously; furthermore this approach is easy to understand for TRIZ newbies, who can quickly generate some innovative ideas, as shows the authors' coaching experience).
2. A second solving approach where EC1 is individually solved by exploring in more detail its causal representation as shown on Figure 2. This is the theme of the next sub-chapter.

5.2. Solving an individual engineering contradiction by expanding and analyzing its causal representation

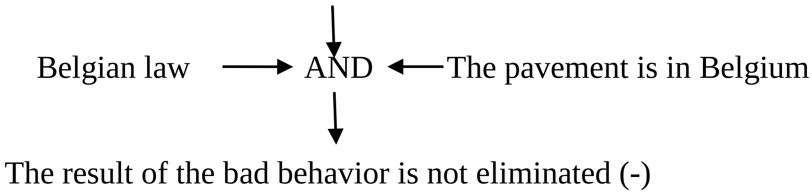
Let us first consider the following example: the embassy of country X is located in a street of Brussels. The embassy has a gate for the entrance and exit of cars and people. The gate is open, and two employees of the embassy discuss together at the gate. A pedestrian is walking down the street, and just before he arrives at the level of the gate, one employee who has just finished his cigarette throws away the cigarette's butt on the pavement. The pedestrian is shocked by this behavior and tells the faulty employee in French that in Belgium such a behavior is prohibited by law, and the Police can give a fine of 50€. Besides, it is not correct to throw waste on the street. The employee does not understand French, but the other employee who is a natural French speaker feels bad about the behavior of his colleague. He is in a kind of contradiction: he does not want to admit the faulty behavior of his colleague, however he would like to eliminate the bad result of the behavior of his colleague, to save his face. If he picks up the butt, he clearly admits the faulty behavior of his colleague. If he does not pick it up, he cannot eliminate the bad result and save the face of his colleague. Let us model the situation as a pair of engineering contradictions formalized as causal chains:

EC1:
He picks up the butt → The bad behavior is recognized (-)
He picks up the butt → The result of the bad behavior is eliminated (+)

EC2:
He doesn't pick up the butt → The bad behavior is not recognized (+)
He doesn't pick up the butt → The result of the bad behavior is not eliminated(-)

Like in ARIZ, let us select one of the two engineering contradictions on the basis of what is the most important for the French speaking employee of the embassy: he absolutely doesn't want to condescend to pick up the butt. Consequently EC2 is selected. Before trying to solve EC2 individually, let us expand the cause-and-effect chain representing EC2.

EC2:
He doesn't pick up the butt → The bad behavior is not recognized (+)
He doesn't pick up the butt → The butt lies down on the pavement



Once the cause-and-effect chain describing EC2 is expanded, this is the analytical phase: there arise opportunities to solve individually EC2 by modifying the root causes (turning them into their opposites) of this cause-and-effect chain so that “the result of the bad behavior is eliminated (+)” while “the bad behavior is not recognized (+)”.

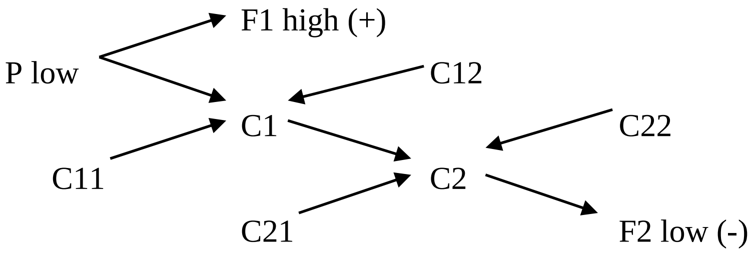
Let us explore some opportunities. Can the Belgian law be changed? Clearly it can’t. Can the country of the pavement be changed? Clearly no, but … if the butt could be put on the pavement of the embassy, EC2 could be solved. But then, how to solve the last remaining conflict? He doesn’t pick up the butt but he puts the butt on the embassy’s pavement. Actually the resolution of this conflict is easy: he just has to push the butt with his foot towards the embassy’s pavement. That’s how it happened in reality.

5.3. Algorithm for an alternative way to solve an individual engineering contradiction

On the basis of this illustrative example, an algorithm for the resolution of any individual engineering contradiction (on the example of EC1) is proposed:

1. Try to solve directly and naturally the individual engineering contradiction formulated as follows: **How to obtain F2 high, while maintaining P low?**

2.1. If this has not succeeded, or if one wants to find other inventive solutions, expand as much as possible the individual contradiction as a cause-and-effect chain; the positive branch of the causal chain corresponds to the high value of F1 and it is unnecessary to expand it; the negative branch of the causal chain, linking P low and F2 low shall be expanded as follows in the general case (the AND operators are present at the level of C1 and C2 but not shown):



2.2. Try to eliminate one root cause, from C11, C12, C21, C22, etc. This means that one must find new conditions to turn one of these arguments into its opposite argument.

2.3. If this has not succeeded, or if one tries to find other inventive solutions, one may apply the 1st step of the present algorithm again and formulate a new, deeper individual engineering contradiction as follows: **How to obtain the opposite of the C1 argument, while maintaining P low?**

6. Conclusion and further discussion

6.1. Conclusion

The chapters 2 to 5 constitute an attempt to explore the resolution of engineering contradictions from a new perspective.

Considering a pair of engineering contradictions (EC1, EC2), the present article focuses on the solving of individual engineering contradictions, i.e. EC1 or EC2, independently from each other. It is shown that this is the same as the solving of the equivalent physical contradiction by the means of satisfaction, which leads to the generation of groups of solutions GS1 and GS2. In order to better visualize what is done during this solving, for instance in an educative context, a 3D representation has been proposed (see Figure 1).

Finally two alternative methods to solve individually an engineering contradiction are proposed. Both methods find their origins in the representation of an engineering contradiction as a cause-and-effect chain (which is in itself not a new topic for TRIZ specialists, see [5] for example) (see Figure 2). It turns out that **the very conflict or contradiction controlling the individual engineering contradiction is between the value of parameter P and the negative, non-wished branch of the cause-and-effect chain**. This is completely different from the conflict or contradiction arising in a pair of engineering contradictions as approached by the Alsthuller matrix which is between the values of the characteristics F1 and F2.

The first method expresses this very conflict through a simple problematic question (for EC1): how to obtain F2 high, while maintaining P low? This formulation helps solving EC1 individually in a direct, natural way. Furthermore this formulation is universal, not specific to the engineering field, and doesn't require any database like in the Altshuller matrix.

The second method requires the expansion of the negative branch of the cause-and-effect chain representing the individual engineering contradiction. This expansion goes in two directions: to find intermediary causes between the two conflicting facts (P low and F2 low, in case of EC1); to find adjacent causes. Solving the individual engineering contradiction requires either the elimination of an adjacent cause or the solving of a deeper conflict between P low and an intermediary cause. This can be done, for example, by using the first method.

These two methods are actually proposed in a single solving algorithm.

6.2. Further discussion and output

The use of the proposed algorithm does not imply to skip the use of the Altshuller matrix. It is originally meant as a complement, as an alternative method. Actually the proposed algorithm cannot explore all groups of innovative solutions, namely the groups Se(ePC) and By(ePC), corresponding to the resolution of the equivalent physical contradiction by the means of separation or bypass. Admittedly the use of the Altshuller matrix allows exploring all the groups of innovative solutions. But the very nature of the innovative solutions generated by the use of the Altshuller matrix is usually not completely clear to the solver: he/she usually doesn't know clearly if one innovative solution corresponds to GS1, GS2, Se(ePC) or By(ePC).

However from this discussion a complete and radical alternative to the use of the Altshuller matrix arises. Actually the use of the proposed algorithm, with the parallel solving of the equivalent physical contradiction by the means of separation and bypass, allows exploring all the groups of innovative solutions. The first interest in doing so is that some limits of the Altshuller matrix as identified in §1 are overcome: the identification of the right parameters of the matrix and the abstract character of the inventive principles. The second interest is that this approach is universal: it applies to any pair of engineering contradictions, and equivalently to any physical contradiction, independently of the field of interest (for instance to business and company organization, but more generally to any field where creativity is needed and where it is possible to express contradictions).

Acknowledgements

I would like to warmly thank four persons, without whom this paper would have never existed (there are many more persons to thank, of course, if one considers the entire cause-and-effect chain of interest). First, TRIZ master Dr Yuri Salamatov, who taught me TRIZ until my current 3rd MATRIZ level, and who trained me to solve engineering contradictions mainly without the use of the Altshuller matrix, i.e. in a more “natural” way. He has inspired me the core of the present paper. Second, TRIZ master Dr Oleg Feygenson, who encouraged me to publish a paper for a TRIZ conference, and who inspired me one key part of this article during a discussion we had about the ways to solve a physical contradiction. Third, my father, who is the best supporter of my journey in the TRIZ world. Fourth, my beloved wife, because she deserves it a lot, and she knows why.

References

1. Darrell Mann. Matrix 2010. IFR Press (2009). 164 pp.

2. Sergei Ikovenko. Personal communication. 2013

3. ARIZ SMVA 91 (E)

4. ARIZ 1995

5. Boris Zlotin, Alla Zusman. Directed Evolution™. Ideation International Inc. (2004). 105 pp.

Author (co-author) to contact: Stéphane Savelli, stephane.savelli@mpsolving.com

TRIZfest 2014

Analysis of Research Trends on Korea's TRIZ

Jiyoung Han[a] , Seung-Hyun Yoo[b]

[a]*Daejin University, Kyungggi-do, 487-711, Korea*

[b]*Ajou University, Kyunggi-do, 443-749, Korea*

Abstract

Since TRIZ was introduced as a tool for technological innovation at the end of the 1990s in Korea, interest in TRIZ has grown largely. With this, studies regarding TRIZ have been actively promoted in various areas not only in the field of technology but also in education, business and design. In particular, companies started to employ TRIZ experts and promote TRIZ education, prompting engineering colleges to expand their course offerings. Since TRIZ education is a creative problem solving technique, it is also widespread among science education institutes for the gifted children and classes for inventions. However, TRIZ education has been promoted somewhat to guide 40 invention principles only in reality.

This study aims to analyze the general trends in TRIZ research since it was introduced 15 years ago, in order to look at the characteristics and problems of TRIZ studies in Korea.

To achieve our goal, we searched all the published academic literature regarding TRIZ including dissertations from universities and other papers using web research in Korea. For search keywords, 'TRIZ' and 'creative problem-solving methods' were used. We found a total of 256 TRIZ-related research papers published in Korea between 1998 and 2013, or for a period of 15 years, and used all the samples for the analysis.

As we observe how those various TRIZ theories are applied in terms of academic areas and levels, we propose to analyze the strengths and weaknesses of Korean TRIZ studies. Such study will serve a basis for the international comparison of TRIZ studies in the future. We expect this to contribute to the academic development of TRIZ as well.

Keywords: Research Trend, TRIZ research, TRIZ analysis criteria

1. Introduction

1.1. Rationale

Having been ruined by the outbreak of the Korean War in 1950, Korea is a nation that generated a form of industrialization known as 'the miracle of Hangang' through strenuous efforts and hard work difficult to find anywhere else in world history. According to the annual report of Britain's Centre for Economics and Business Research (CEBR), Korea is among the top 15[t] in the world as of 2013 in terms of economic scale (chosunBiz, 2014). However, the speed of Korea's economic development is gradually slowing down due to Korea's aging population and the rapid progress of surrounding developing countries, including China.

The new government formed in 2013 is initiating Korea's development to become an advanced country through economic innovation. As part of this process, strategies such as becoming a 'creative economic town' or 'building a creative economic ecological system' are being realized. Accordingly, the greatest topic among the many policies initiated by the government is ‘creativity.’ This signifies the demand for the conversion of Korea from being a ‘fast follower’ to becoming a ‘first mover’ in each social field, with regard to becoming an advanced country.

This topic over the entire society is naturally emphasizing interest on the tools to foster creativity. Various creativity development tools are being introduced, and among these tools, TRIZ applied by major Korean conglomerates is emerging as an alternative tool.

Developed by Altsuller, TRIZ is not a simple problem solving method; it proposes a creative problem solving direction and inventive principle to address problems based on common principles extracted from numerous excellent patents. TRIZ is a strong tool that was researched based on logical science to help resolve inventive problems. TRIZ began in the Soviet Union and has been used in various fields. Altsuller’s book became widely known in 1984, which led to the interest of American companies including Microsoft, GE, and Ford, obtaining good results through the application of TRIZ. TRIZ was introduced in Korea in 1996, and is gradually broadening its scope of application towards improving the performance of products manufactured by large companies such as LG, Samsung, and POSCO.

The application of TRIZ has also spread to the education industry. TRIZ was implemented in Korean universities particularly in engineering problem solving and creative design education. It is also diversely applied in elementary and middle school education for creative development. TRIZ is also applied in various fields other than engineering.

Consequently, studies related to the application of TRIZ in Korea are diversifying with regard to quantity and the field and subject of study. However, in many cases, users consider the use of TRIZ complex, as well as users who claim to know TRIZ while using only minor parts of the product. Further, there are existing studies (Park, S. et al, 2011) on the analysis of TRIZ research trends in Korea, but these studies have limitations in comprehending how and to what degree the TRIZ-related theory is applied, as they do not conduct the analysis based on the system of TRIZ theory.

Korea is one of the countries that most frequently apply TRIZ on industrial sites. However, there are no systematic studies on how TRIZ-related research is conducted. Accordingly, this study intends to discover the problems and improvement directions of TRIZ-related research by analyzing research trends, 15 years after the introduction of TRIZ in Korea.

1.2. Objectives of Study

By analyzing TRIZ-related research over the past 15 years, or from 1998 to 2013, this study intends to identify Korea’s TRIZ research trends and to propose implications for setting a direction for future TRIZ research. Detailed research goals to achieve such research purpose are as follows.

First, the criteria for TRIZ research trend analysis are set.

Second, the annual TRIZ research trend is analyzed.

Third, the research trend of each TRIZ topic is analyzed.

Fourth, the implications for setting systematic research and future research directions are proposed.

2. Method of Study

2.1. Subject of Analysis

The subjects in this study are 256 published studies, including 149 studies in academic journals, 97 master theses, and 10 doctorate theses, over the past 15 years from 1998 to 2013.

For thesis search, the thesis database provided by the National Assembly Library, as well as Google Scholar, KISS, and RISS have been used, and keywords for data search included 'creative problem solving method' and 'TRIZ.' The ratio of topics used in this study include 149 studies in academic journals accounting for 58.3%, 97 master theses accounting for 37.8% and 10 doctorate theses accounting for 3.9%.

2.2. Criteria for Analysis

The criteria for the analysis of TRIZ research trends were largely categorized into three. First, with respect to the topic selection, the topic of TRIZ was extracted based on a book called 'Tetris' (Cascini et al, 2009) published for the expansion of TRIZ education in Europe, which was classified with the advice of three TRIZ professionals. These included two internationally certified level 4 TRIZ professionals and one internationally certified level 3 TRIZ professional. Second, the criteria for the research method and research subjects (applied subjects, section of educational courses) were extracted by referring to literature related to research trends. Third, because the field of application of TRIZ is extremely broad, the 254 studies were collected and inductively categorized based on scope of application.

Within this process, discussions were made with 3 TRIZ professionals and 2 engineering education research doctors to continually edit and supplement the criteria of analysis. The final deduced analysis criteria are as shown on <Table 1>.

Table 1

TRIZ Research Trend Analysis Criteria

Published Year	Research Item	Research Method	Research Subjects		
			Field of Educational Course	Academic Field	Subject of Application
1998 ~ 2013	* 39 Parameters * Contradiction matrix * 40 invention principles * Physical contradictions (Principle of separation) * Substance field model * Ideality * Resources * Rule of technical evolution * Scientific effects * ARIZ * Other	* Experiment * Observation * Research * Case Study * Literature Study * Combined Study	* Textbook * Non-textbook	* Mechanical * Architectural * Electrical * Chemical Engineering * Industrial Engineering * Design * Management * Education * Other	* Elementary, Middle, High Schools * Universities * Industrial groups

3. Theoretical Background

3.1. Literature Review for the Categorization of TRIZ-related Study Topics

TRIZ is the abbreviation containing the Russian initials of 'Theory of Inventive Problem Solving,' which was created by Russia's Genrich S. Altshuller through research and systematization of numerous inventive patents to integrate the TRIZ theory.

Altshuller statistically analyzed 200,000 patents, in order to deduce principles that can be used as problem solving methods, by observing the repeated use of the same principles in patents from different areas and eras. He emphasized the fact that the hint of the resolution would be effective when used in technologies of other fields.

The methodology of solving various industrial problems includes QC (Quality Control) and VE (Value Engineering) (Lee, J. W. et al, 2007). If QC is the method of resolution that discovers problems based on phenomena and pursues causes and factors, VE is a method that promotes value enhancement by improving the balance of the function and cost of products and services by setting the 'ideal state' from customer demands and analyzing how such can be realized. However, the resolution cannot be proposed solely from VE. Specifically, the definition of functions obtained by proposing problems in VE can lead to a very independent resolution if the definition is analyzed with TRIZ.

As such, TRIZ is a system that helps resolve problems, wherein the structure of the system is composed of various criteria including theoretical core, methods, and algorithms (Kang, B. S. et al, 2012). As shown in Fig. 1, basic methodologies are based on philosophy, natural science and psychology, but the methodology of TRIZ is based on the theory of algorithmic aspects.

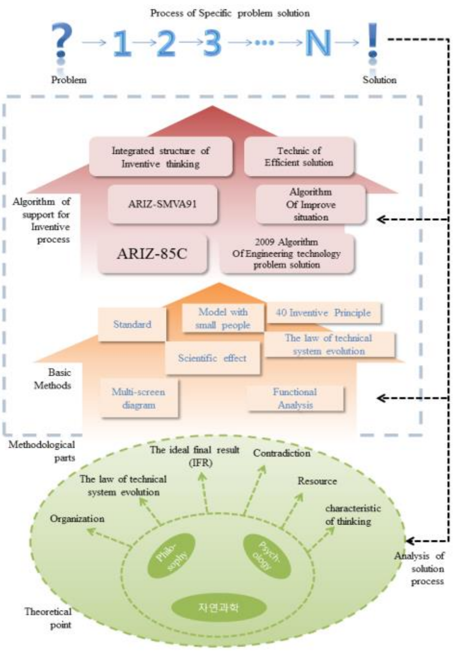


Fig. 1. TRIZ Structure (Kang, B. S. et al, 2012)

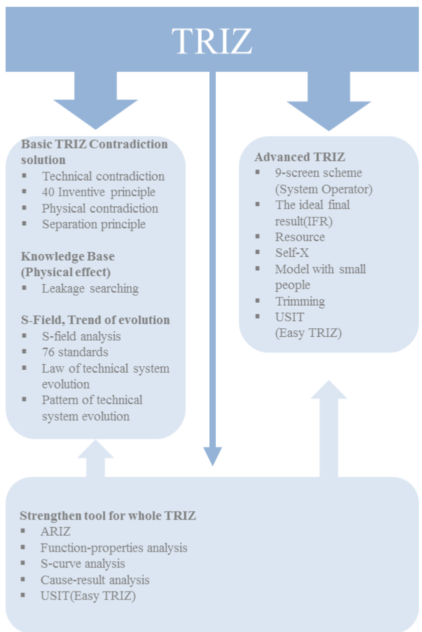


Fig. 2. TRIZ System (Lee, J. S. et al, 2007)

Lee, J. W. et al (2007) categorizes and proposes the TRIZ system into three dimensions: basic tools, progressive tools and tools that reinforce the entire TRIZ system (see Fig. 2). In other words, there are basic tools such as 'contradiction,' 'substance field analysis,' 'rule of technological evolution,' and 'scientific effects,' and progressive TRIZ tools, such as '9

Window,' 'ideality,' and the 'dwarf model.' Additionally, there are tools that reinforce the entire TRIZ system, such as 'ARIZ,' 'functional/property analysis,' and 'cause/result analysis.'

3.2. Literature Review Related to Research Trends

A study of studies refers to the critical analysis of existing research, specifically, the interpretation of evaluated values and reevaluating the value of evidence related to validity (Ko, H. et al, 1988).

Existing studies conducted for the development of criteria to analyze topics including TRIZ for the analysis of TRIZ-related research trends are as follows.

For the analysis of research trends related to specialized high school education, KIM, Y. et al (2011) largely categorized the research properties and research subjects, and categorized the scope of research properties into research period, type of publication, research field, data collection, and research method as well as set organization, region, applied subjects and types of applied subjects for the scope of research topics.

Rho, T. et al (2013) studied the criteria of research trends of engineering education research thesis in terms of published year, organization of the first author, research field and research method. The applied research fields included engineering education philosophy and policy, engineering education method and program development, engineering education cases and lecture content, engineering education verification and evaluation, and other components. Lastly, the applied research methods included literature and development study, research, and experiments.

Jang, H. et al (2013) analyzed 279 HRD-related studies in the study of HRD issues and trend exploration on the criteria of research topic, HRD process, research method and researcher's organization. Research methods were categorized into four scopes: quantitative research, qualitative research, theoretical research, and practical research.

Park, S. et al (2011) used the criteria of: type of publication, research topic, research method, research subjects, and researcher's properties to analyze TRIZ research trends. The research topic was categorized into product development, knowledge management, education application, concept design, problem-solving process, quality management, TRIZ theory and other. The research method included literature research, case study, experiments, research, development research, and comparative analysis. The research subjects were categorized into personal subjects, physical subjects, and academic subjects.

As such, existing studies on research trends categorized and proposed the criteria for analysis into research topic, research method, and research subjects, wherein the scope of research subjects had the following sub-categories: educational process, academic field, and applied subjects.

4. Research Results

4.1. Annual Trends Analysis of TRIZ Research

The results of analyzing research studies each year over the past 15 years, from 1998 to 2013, with regard to research topic, research method, and research subjects are as follows.

Results of the time series trend analysis of TRIZ research topics are shown on <Table 2>. Specifically, the result of categorizing per criterion displayed 123 studies among a total of 256 studies using the TRIZ tool together with more than two other tools, accounting for 38.2%; with 99 studies using technical contraction accounting for 38.9%; 8 studies individually using physical contradiction and substance field model, accounting for 3.2%; 5 studies using ideality, scientific effect, and ARIZ, accounting for 1.9%; and 2 studies using the principle of technical evolution accounting for 0.8%.

With regard to the tool, 40 invention principles accounted for 25.5%, at 65 studies out of the 256 total, and the most commonly used tool among technical contradiction tools accounted for 65.6%.

The analysis per year displayed more than 20 studies being published in Korea each year since 2006, after the gradual increase in publications since 2004, following the introduction of TRIZ studies in 1998 in Korea. Studies concerning technical contradictions were the main concern of studies in the early years of TRIZ studies. However, since 2004, the use of TRIZ tools has become diversified. TRIZ studies that used 40 invention principles were conducted at a consistent ratio. ARIZ, however, which uses algorithm modeling, displayed declining research performance since the first publication in a research in 2007. Such results are evident of the fragmentary application of TRIZ studies, and the passive application of algorithms connected to general problem-solving processes.

Table 2

Annual Trends of TRIZ Research Topics (frequency, %)

Topic / Year	Technical Contradiction			Physical Contradiction	Substance Field Model	Ideality	Resources	Principles of Technical Evolution	Effects	ARIZ	Other *	Total 39 Parameters
	39 Parameters	Contradiction Matrix	40 Invention Principles									
1998	2(0.8)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1998	2(0.8)
1999	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1999	0(0)
2000	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2000	1(0.4)
2001	0(0)	1(0.4)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2001	0(0)
2002	0(0)	2(0.8)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2002	0(0)
2003	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(0.8)	0(0)	2003	0(0)
2004	0(0)	1(0.4)	1(0.4)	0(0)	1(0.4)	1(0.4)	0(0)	1(0.4)	1(0.4)	0(0)	2004	0(0)
2005	0(0)	2(0.8)	0(0)	2(0.8)	0(0)	1(0.4)	0(0)	0(0)	0(0)	0(0)	2005	0(0)
2006	1(0.4)	1(0.4)	6(2.4)	1(0.4)	1(0.4)	0(0)	0(0)	0(0)	1(0.4)	0(0)	2006	1(0.4)
2007	0(0)	1(0.4)	6(2.4)	0(0)	2(0.8)	0(0)	0(0)	0(0)	0(0)	1(0.4)	2007	0(0)
2008	0(0)	1(0.4)	3(1.1)	1(0.4)	1(0.4)	1(0.4)	0(0)	0(0)	0(0)	2(0.8)	2008	0(0)
2009	1(0.4)	4(1.6)	7(2.7)	1(0.4)	0(0)	1(0.4)	0(0)	0(0)	0(0)	0(0)	2009	1(0.4)
2010	1(0.4)	3(1.1)	7(2.7)	1(0.4)	2(0.8)	1(0.4)	0(0)	1(0.4)	1(0.4)	2(0.8)	2010	1(0.4)
2011	2(0.8)	1(0.4)	14(5.5)	1(0.4)	1(0.4)	1(0.4)	0(0)	0(0)	0(0)	0(0)	2011	2(0.8)
2012	2(0.8)	4(1.6)	9(3.5)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2012	2(0.8)
2013	1(0.4)	1(0.4)	10(3.9)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2013	1(0.4)
Total	11 (4.4)	23 (9.0)	65 (25.5)	8 (3.2)	8 (3.2)	6 (2.4)	0 (0)	2 (0.8)	5 (1.9)	5 (1.9)	Total	11 (4.4)

* When two or more concepts among TRIZ theory and methodology, 6Signma, ASIT, and MFTM-TRIZ coexist.

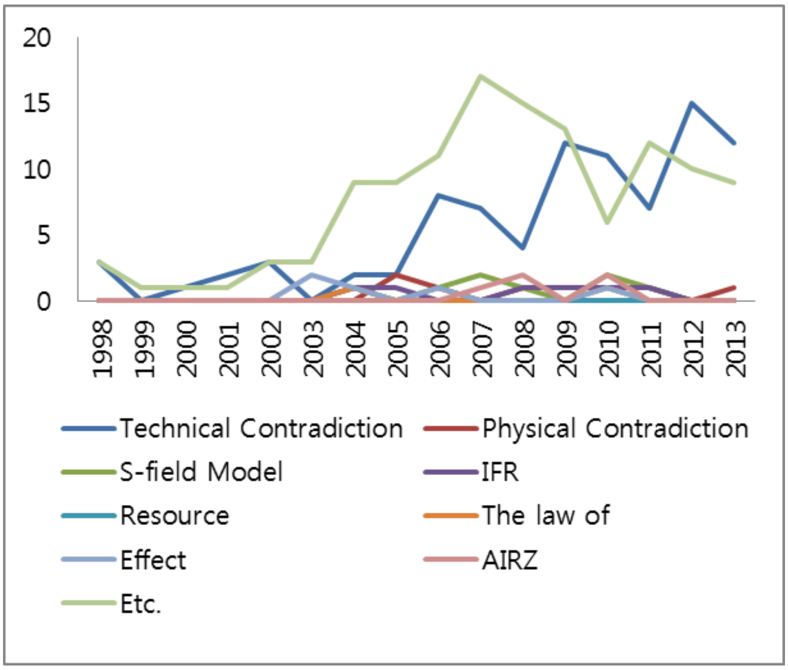


Fig. 3. Annual Trends of TRIZ Research Topics

Table 3

Annual Trends of TRIZ Academic Fields (frequency, %)

Academic Field / Year	Engineering						Non-Engineering			Other*	Total
	Mechanical	Architectural	Electrical	Chemical	Industrial	Other	Design (Art)	Management	Education		
1998	1(0.4)	0(0)	0(0)	0(0)	2(0.8)	0(0)	0(0)	1(0.4)	0(0)	2(0.8)	6(2.3)
1999	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	1(0.4)
2000	1(0.4)	0(0)	0(0)	0(0)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	2(0.8)
2001	0(0)	0(0)	0(0)	0(0)	1(0.4)	0(0)	0(0)	1(0.4)	0(0)	1(0.4)	3(1.1)
2002	3(1.1)	1(0.4)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	6(2.3)
2003	2(0.8)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	0(0)	1(0.4)	5(1.9)
2004	2(0.8)	1(0.4)	1(0.4)	0(0)	2(0.8)	0(0)	1(0.4)	2(0.8)	0(0)	6(2.3)	15(5.8)
2005	6(2.3)	0(0)	1(0.4)	1(0.4)	2(0.8)	0(0)	0(0)	0(0)	1(0.4)	3(1.1)	14(5.5)
2006	6(2.3)	0(0)	0(0)	2(0.8)	1(0.4)	0(0)	1(0.4)	1(0.4)	5(1.9)	6(2.3)	22(8.7)
2007	12(4.8)	1(0.4)	1(0.4)	1(0.4)	1(0.4)	1(0.4)	2(0.8)	4(1.6)	3(1.1)	1(0.4)	27(10.6)
2008	13(5.1)	0(0)	0(0)	0(0)	6(2.3)	0(0)	0(0)	2(0.8)	1(0.4)	2(0.8)	24(9.5)
2009	8(3.3)	2(0.8)	2(0.8)	0(0)	2(0.8)	0(0)	1(0.4)	3(1.1)	7(2.6)	3(1.1)	28(10.8)
2010	13(5.1)	0(0)	2(0.8)	0(0)	0(0)	1(0.4)	2(0.8)	1(0.4)	2(0.8)	3(1.1)	25(9.8)
2011	8(3.3)	1(0.4)	2(0.8)	0(0)	0(0)	0(0)	4(1.6)	5(1.9)	7(2.6)	5(1.9)	32(12.6)
2012	6(2.3)	2(0.8)	1(0.4)	0(0)	0(0)	1(0.4)	5(1.9)	0(0)	6(2.3)	4(1.6)	25(9.8)
2013	4(1.6)	4(1.6)	2(0.8)	2(0.8)	1(0.4)	0(0)	3(1.1)	2(0.8)	3(1.1)	1(0.4)	22(8.7)
Total	85 (34.2)	13 (5.2)	13 (5.2)	6 (2.4)	19 (7.5)	3 (1.2)	19 (7.4)	23 (9.0)	35 (13.2)	40 (15.4)	256 (100)

* Refers to cases applied on the TRIZ theory and political fields.

With regard to the analyzed studies, 139 of the 256 studies were in the field of engineering, accounting for 54.5%; and 77 studies were in the field of non-engineering, accounting for 29.6%. Among the engineering studies analyzed, 85 studies dealt with mechanical engineering, which accounted for 34.2% of the entire 256 studies analyzed, and 61.2% involved engineering studies, followed by industrial engineering (7.5%), architectural and electronic engineering, individually accounting for 5.2%, chemical engineering (2.4%), and other (1.2%). In the non-engineering field, the topic of education was the field that most actively conducted TRIZ-related studies at 35 studies (13.2%), followed by management (23 studies, 9.0%), and design (19 studies, 7.4%).

The annual trend in the field of research displays an increase in TRIZ research in the engineering field with the diversification of TRIZ topics after 2004, and most studies were published in 2007. This trend also affected the non-engineering field to cause active research, mainly in the educational field since 2006. Further, the attempt to incorporate TRIZ in the management field is increasing, resulting in the continued publication of related studies since 2007. The interesting fact is that TRIZ is also being applied in design-related studies since 2011, with the expansion of STEAM education in Korea.

The results of analyzing the research methods used in TRIZ studies are shown on <Table 4>. Among a total of 256 subjects, 108 studies used the case study method (42.7%), followed by experimental research (26.5%), literature research (14.0%), research (10.3%), combined research (5.4%), and observational research (1.6%). The more frequent use of case studies and experimental research is attributed to the academic characteristic of TRIZ, which requires the analysis of cases with actual application of TRIZ on problem solving, or experiments that verify the effect of applying TRIZ on actual problem situations.

Table 4

Annual Trends of TRIZ Research Methods (frequency, %)

Research Method / Year	Experimental Research	Observation	Research	Case Studies	Literature Research		Combined Research	Total
					Developmental	Theoretical		
1998	0(0)	0(0)	0(0)	4(1.6)	1(0.4)	1(0.4)	0(0)	6
1999	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	0(0)	1(0.4)
2000	0(0)	0(0)	0(0)	2(0.8)	0(0)	0(0)	0(0)	2(0.8)
2001	0(0)	0(0)	1(0.4)	2(0.8)	0(0)	0(0)	0(0)	3(1.1)
2002	0(0)	0(0)	2(0.8)	2(0.8)	0(0)	0(0)	2(0.8)	6(2.4)
2003	0(0)	1(0.4)	0(0)	4(1.6)	0(0)	0(0)	0(0)	5(1.9)
2004	2(0.8)	0(0)	2(0.8)	4(1.6)	0(0)	7(2.6)	0(0)	15(5.8)
2005	5(1.9)	2(0.8)	1(0.4)	6(2.4)	0(0)	0(0)	0(0)	14(5.4)
2006	5(1.9)	0(0)	4(1.6)	11(4.3)	0(0)	2(0.8)	0(0)	22(8.7)
2007	6(2.4)	0(0)	2(0.8)	17(6.6)	1(0.4)	0(0)	1(0.4)	27(10.5)
2008	5(1.9)	0(0)	0(0)	10(3.9)	4(1.6)	2(0.8)	3(1.1)	24(9.5)
2009	9(3.5)	0(0)	4(1.6)	8(3.3)	5(1.9)	0(0)	1(0.4)	27(10.5)
2010	10(3.9)	1(0.4)	0(0)	8(3.3)	1(0.4)	2(0.8)	3(1.1)	25(9.8)
2011	12(4.8)	0(0)	3(1.1)	10(3.9)	3(1.1)	1(0.4)	3(1.1)	32(12.6)
2012	11(4.3)	0(0)	1(0.4)	11(4.3)	1(0.4)	0(0)	1(0.4)	25(9.8)
2013	3(1.1)	0(0)	6(2.4)	9(3.5)	4(1.6)	0(0)	0(0)	22(8.7)
Total	68(26.5)	4(1.6)	26(10.3)	108(42.7)	20(7.8)	16(6.2)	14(5.4)	256(100)

A total of 54 studies were related to education, with 49 studies dealing with elementary, middle, and high schools and accounting for the highest ratio at 90%. This is attributed to the increasing attempt to use TRIZ in education, such as inventive class and savant classes for fostering creativity. Further, the application of TRIZ in engineering courses and the establishment of TRIZ-related courses in universities is increasing. Meanwhile, there are relatively low study results for TRIZ education applied in the industrial labor force.

Twenty studies from a total of 28 studies in the educational field applied TRIZ on regular educational courses, accounting for 71.5%, while 8 studies applied TRIZ on irregular educational courses, accounting for 28.5%.

4.2. Analysis of Research Trends Per TRIZ Study Topic

A cross analysis was conducted on the research methods and research subjects to determine the trends per TRIZ research topic.

Analysis of the research methods per research topic yielded a technical contradiction with case studies used almost as much as experimental research. Case studies were most frequently used concerning combined topics that use more than two TRIZ tools. This signifies the common use of more than two TRIZ tools in case studies that apply TRIZ tools in actual problem-solving situations.

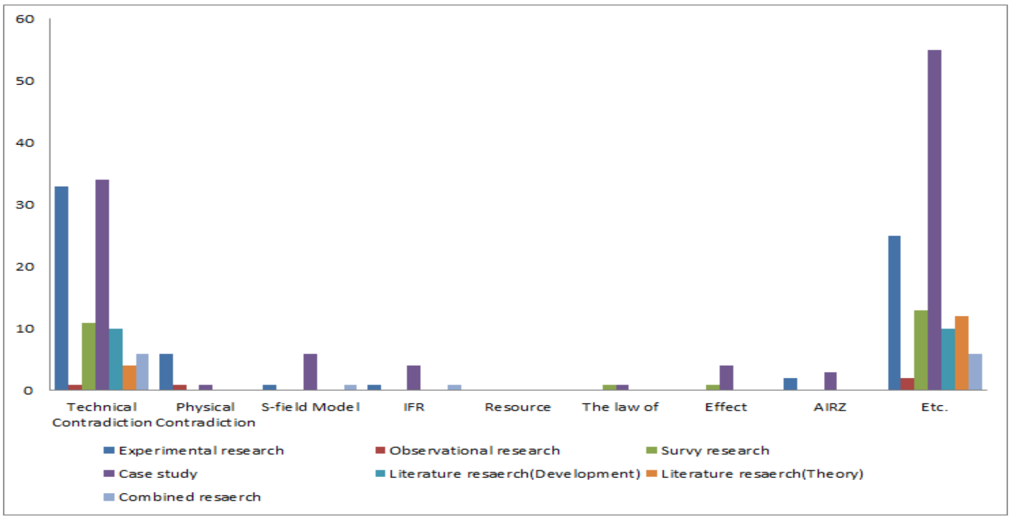


Fig. 4. Cross Analysis Results between TRIZ Research Topics and Research Types

Table 5

Cross Analysis Results between Academic Fields and TRIZ Research Topics (frequency, %)

Research Topic \ Academic Field		Engineering: Mechanical	Engineering: Architectural	Engineering: Electrical	Engineering: Chemical	Engineering: Industrial	Engineering: Other	Non-Engineering: Design	Non-Engineering: Management	Non-Engineering: Education	Other	Total
Technical Contradiction	39 Parameters	7(2.6)	0(0)	0(0)	0(0)	3(1.1)	0(0)	0(0)	0(0)	0(0)	1(0.4)	11(4.4)
	Contradiction Matrix	10(3.9)	5(1.9)	1(0.4)	0(0)	3(1.1)	0(0)	1(0.4)	2(0.8)	0(0)	1(0.4)	23(9.0)
	40 Invention Principles	13(5.1)	1(0.4)	2(0.8)	3(1.1)	2(0.8)	2(0.8)	10(3.9)	8(3.3)	18 (7.1)	6(2.4)	65 (25.8)
Physical Contradiction		6(2.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	1(0.4)	8(3.2)

Substance Field Model	6(2.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	2(0.8)	8(3.2)
Ideality	2(0.8)	0(0)	0(0)	0(0)	0(0)	0(0)	1(0.4)	1(0.4)	2(0.8)	0(0)	6(2.4)
Resources	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)
Principles of Technical Evolution	0(0)	0(0)	1(0.4)	0(0)	0(0)	0(0)	1(0.4)	0(0)	0(0)	0(0)	2(0.8)
Scientific Effects	3(1.1)	0(0)	0(0)	0(0)	1(0.4)	0(0)	0(0)	0(0)	0(0)	1(0.4)	5(1.9)
ARIZ	4(1.6)	0(0)	1(0.4)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	5(1.9)
Other	34 (12.9)	7(2.6)	8(3.3)	3(1.1)	10(3.9)	1(0.4)	6(2.4)	12 (4.8)	14 (5.4)	28 (11.0)	123 (48.2)
Total	85 (33.3)	13 (5.1)	13 (5.1)	6 (2.4)	19 (7.5)	3 (1.1)	19 (7.5)	23 (9.0)	35 (13.7)	40 (15.6)	256 (100)

As illustrated in <Table 5>, the cross analysis results of each TRIZ research topic and academic field displayed TRIZ research to be most actively conducted in the field of mechanical engineering, wherein various TRIZ tools are used. Most academic fields used technical contradiction to resolve TRIZ problems, with the 40 Invention Principles as the most frequently used. Particularly in the educational field, studies that account for approximately 50% of the total 35 studies were analyzed to use 40 Invention Principles, as being the most easily understood TRIZ tool by students.

As the understanding of TRIZ broadens, problem-solving using ARIZ is recommended. Academic fields that use ARIZ are limited to mechanical engineering and electronic engineering so the application of TRIZ is generally low.

5. Conclusion

The TRIZ research trends concluded by this study are as follows.

First, academic journals are the most frequent form of publication of TRIZ-related studies, followed by master's degree theses, and doctorate theses. A comparison of the number of published studies in academic journals shows the continued increase of published master's degree theses.

Second, frequency analysis of used TRIZ research topics reveal two or more TRIZ tools to be the most frequently used topic, followed by technical contradiction. This signifies that it is easier to solve problems when various TRIZ tools are used, rather than applying a single TRIZ tool while technical contradiction is considered to be actively used as it allows the relatively easy understanding of TRIZ.

Third, the use of TRIZ research topics has increased and diversified each year. This is interpreted to be based on the increased understanding of TRIZ, as it spreads. However, users still lean towards the basic methods, including technical contradiction, so there is a need for the expansion and application of ARIZ, as the algorithm that supports creative inventive process.

Fourth, case studies and experimental research are the most frequently used methods in TRIZ-related research. This is because various TRIZ tools were applied on problem solving situations, which were directly proposed as the research result. Case studies were frequently used for technical contradiction, due to the high usability of case studies because of the structured system of technical contradiction compared to other TRIZ tools.

Fifth, the use of TRIZ is increasing in the educational field. Specifically, it was noted that TRIZ was used in creativity education with the use of 40 invention principles in elementary, middle, and high schools.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF-2013R1A1A3010623).

References

1. Cascini, G. et al. TETRIS: Teaching TRIZ at School, Education and Culture DG, 2009.

2. Jang, H. et al., “Inquiry into HRD Issues and Trends through the Analysis of Korean HRD Journal Articles”, Journal of The Korean Society of Human Resource Development, 2013, vol. 15, #2, pp.1-22.

3. Kim, Y. el al. “Analysis of Research Trends in Cooperation between Industry and Specialized High School”, Journal of Korean Institute of Industrial Education, 2011, vol. 36, #1, pp.95-114.

4. Ko, H. et al, Foundations of Social Behavioral Research, Sungwon Publishers, 1988.

5. Park, S. et al., “The Analysis on Research Trends related to TRIZ in Korea”, Journal of Korean Practical Arts Education, 2011, vol. 17, #2, pp.215-236.

6. Rho, T. et al., “Analysis of Research Trend in Journal of Engineering Education Research”, Journal of Korean Institute of Industrial Education, 2013, vol. 16, #1, pp.45-53.

7. News 1 Korea. Korean Economy, 15th in the World to the 11th by 2028. Retrieved May 7, 2014 from http://news1.kr/articles/1470472

8. ChosunBiz. To Enter the ‘Era of a National Income of 40 Thousand Dollar’ as Mentioned by President Park. Retrieved May 7, 2014 from http://biz.chosun.com/site/data/html_dir/2014/01/06/2014010603123.html

TRIZfest 2014

Application of TRIZ Approach in the Research of Seismic Resistance

Frantisek Palcak

Institute of Applied Mechanics and Mechatronics. 812 31 Bratislava, Slovak Republic

Abstract

The successful development of breakthrough technical systems requires necessary tools (existing knowledge in the form of know-how, techniques, software), hardware (infrastructure), but the most important prerequisite is the ability of people who are building new roads (degree of articulation of knowledge, skills and creativity).

Basic motivation for this paper is to show the potential of TRIZ approach how to improve existing and invent new mechanisms by combination of existing local deterministic methods (NVH analyses based on statistical data on properties of materials, and dynamic load effects,...) with systematic global creative methods (AFD-TRIZ,...).

In the paper is shown the historical transition from scalar, vector, matrix, and quaternion formalism to the subgroup formalism, also the simplification of the mathematical model to achieve high computational efficiency of numerical methods.

Application of the objective laws derived from development of technical systems was used in the case of development of positioning mechanisms. The research of appropriate structure for positioning mechanisms from point of view of seismic resistance shows the necessity to combine open structure of mechanisms by redundantly actuated parallel structure.

In the paper there are some results from research of seismic resistance of air flow regulator using method AFD-TRIZ.

The article pointed out that during examining seismic safety in addition to the real and computer experiments it is necessary to take into account the creative approach that helps overcome the inertia of thinking.

Keywords: analysis, synthesis, mechanisms, seismic resistance, evolution, TRIZ approach.

1. The potential of TRIZ approach

The three primary findings were discovered by Altshuller during research of many patents:
1. Problems and solutions are repeated across industries and sciences.
2. Patterns of technical evolution are also repeated across industries and sciences.
3. In significant innovations the scientific effects are used outside the field where innovations were developed.

The concept of identifying the contradictions in a design and correlating them to how other inventors have solved the same types of problem is most important element of TRIZ methodology covering following building blocks:

Postulates from theoretical foundations:
- objective evolution laws from patterns of improvement of technological systems classified in terms of generic function based on parameters,
- law of contradictions between antagonistic requirements,
- law about conditions (specific circumstances and resources) for improvement of system,

Analytical tools serving as problem models in the form of:
- assignment solving process (hill, tongue, funnel),
- descriptions (ENV: Element-Name-Value, analyses: Function, Su-Field, Contradiction),
- thinking about system,
- ARIZ for complex problems,

Knowledge based tools for suggestion of standard solutions:
- 40 Inventive Principles [2],
- system of 76 inventive standard solutions for Function Analysis,
- database with sources of scientific effects with a function-based structure.

TRIZ approach enables to find differences between similar things by systematic analysis, identification, separation and extraction using left part of a brain, and to find similarities between different things by creative synthesis, solution, generalization and unification in the right part of a brain. Users will obtain the ability to make generalized analogy to compile baseline model, to think simultaneously from a point of view of thought (ontogenetically) and of the development of techniques (filogenetically), ability to work with statistical tools to detect a multidisciplinary context.

2. The computational efficiency of complex virtual models

The lower levels of classification of learning objectives within education and research (knowledge, comprehension and application) help us learn to replicate what has already been done elsewhere while the higher levels (analysis, synthesis and evaluation) drive innovation. [1] (Bloom, 1956).

2.1. The quantitative and qualitative properties

Quantitative properties of Functional virtual prototype (FVP) as deterministic object we can uniquely identify and algorithmise, because they are bound by explicit relationships. For example, the number and type of members and connections uniquely determine the number of basic loops and corresponding number of equations of the mathematical model of FVP.

Qualitative properties of FVP result from deterministic chaos in the form of unlimited number of fluctuations, so we can not predict them uniquely. For example, driveability of vehicle FVP result from interactions vehicle - the terrain, also singular features of FVP are the result of a system configuration. Therefore, it needs the active participation of the user to achieve the qualitative properties of FVP.

Quantitative properties of the course of deterministic chaos can not be uniquely predicted, but we can automate its operation. Qualitative properties of deterministic chaos can be determined by the active participation of the user.

For example, the iterative process of integration takes place automatically, without user intervention, and it is not possible to predict the number of iterations in each step to achieve the required accuracy, but we can clearly prescribe permissible tolerance.

Properties of FVP as deterministic object and actions of solvers as deterministic chaos show that the process of designing the product will always be needed by the active participation of user of computer technologies and work with FVPs, which have more complex features will require increasingly higher demands on multidisciplinary training of user.

There we see the potential of TRIZ approach [2] (Altshuller 1998), how to improve existing and invent new mechanisms by combination of existing local deterministic methods with systematic global creative methods. Our mission is to understand the principle of properties of nature through observation and experimentation, then to find a concise form of generalized laws and to apply gained knowledge via humane way to creation of new works. Algorithmic tasks with new unknown elements but known methods of solution support a convergent, inertial thinking. Heuristic tasks with procedure which is new and discovered in the process of solving supports imagination, creative, original divergent thinking in finding solutions.

2.2. Development of the mathematical formalism

Development of mathematical formalism in mechanics is associated with the increasing complexity of an inspected object. In describing the motion of objects (point, body, system of bodies) the hierarchy of complexity graduates: motion of a point (along straight line, curve in the plane, in space), translational motion of a body (straightforward, curvilinear), rotational motion of a body, general body motion in plane (the method of Cauchy, Poisson), the simultaneous motions of bodies (resulting, carrying, local relative), spherical motion (Euler method, Cardan, ...), and spatial motion of the body (method of Cauchy, Poisson), (method of Mozzi, Chasles).

From the algebraic equations with scalar quantities, sufficient to study the static properties, it was necessary to transit to the vector algebra for planar tasks, and to the matrix calculus for spatial tasks while studying the movement of bodies. For description of the inertial properties of bodies the tensors are used, and for nonsingular description of position of spherical body motion the quaternions appear as suitable formalism.

In the methods of synthesis of new topology for parallel mechanisms that have practical use, as a suitable formalism were used Lie subgroup of the displacement Lie group, [3] (Huynh, Hervé, 2003). To describe increasing complexity of an inspected motion it is necessary to use increasing complexity of mathematical formalism with concise formulation (Fig.1).

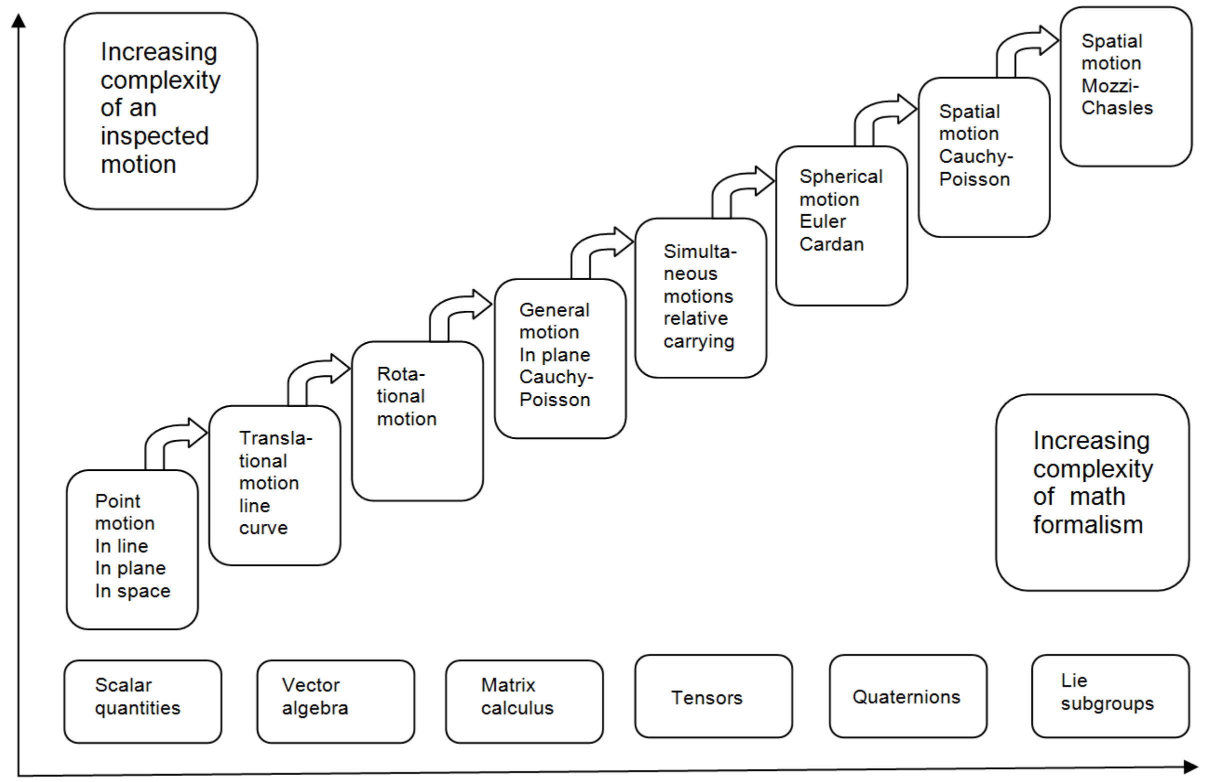


Fig. 1. The increasing complexity of an inspected motion and mathematical formalism

2.3 Computational efficiency of numerical methods

The nuclear plants have lot of complicated equipment with huge virtual models. Such complex models are computationally inefficient for determination of sensitivity to seismic excitations, dynamic load, and strength analyses. Thus the goal is to increase convergence, speed and accuracy of computational efficiency of such complex virtual models.
The traditional solution strategy is oriented to boost the computational power of HW which increase cost and leads to unwanted conventional compromise (trade-offs).
The role of TRIZ is to enable us to achieve high computational efficiency of complex virtual model without compromise. The root cause of solution lies in:

- identification of apparently paradoxical contradiction statement (to achieve high computational efficiency without necessity to increase of computational power of HW) as most important aspect of TRIZ, and subsequently in

- use of appropriate TRIZ tools in the approach how to eliminate compromises.

The Contradiction Matrix provides a chance to looking for Inventive Principles (IP) in which was in past solved similar generic types of contradiction:

#1 Segmentation: The dynamic content of continuum can be replaced by sum of eigenshapes.
#2 Extraction: The inactive eigenfrequencies, which are out of working excitation, are switched-off in the MNF file of flexible body.
#7 Nesting: Component Mode Synthesis representation of complex dynamic content by sum of simple mode shapes.
#10 Prior action: Simplification of complex virtual model by Hurty-Craig-Bampton modal reduction.
#33 Homogeneity: The same mathematical model of LAE is used for all types of analyses.
#35 Transformation properties: Conversion of DAE to the system of ODE, ODE to the system of NAE, and NAE to the system of LAE.

The high computational efficiency of complex virtual models was achieved in three steps:
- simplification of complex virtual model by Hurty-Craig-Bampton modal reduction (IP: #1, 7, and 10),
- switch-off the inactive eigenfrequencies, which lay out of working excitation spectra in the MNF file of flexible body (IP: #2), and
- conversion of DAE mathematical model to the system of LAE (IP: #33, 35).

To achieve high computational efficiency of numerical methods (speed, convergence, accuracy) it was necessary to convert complex mixed system of differential equations of motion and binding algebraic equations (DAE), which represent the mathematical model of the mechatronic product (MBS), to the more numerically stable system of ordinary differential equations (ODE). But solving (ODE) requires expensive evaluations of Jakobi matrix, therefore it was more suitable to convert (ODE) to the system of nonlinear algebraic equations (NAE). In order to employ the fastest numerical methods (Calahan) it was necessary to linearize (NAE) by the Newton-Raphson approximation using Taylor series to a system of linear algebraic equations (LAE), [4] (Orlandea, Chace, Calahan, 1976).

To achieve increasing computational efficiency of numerical methods it is necessary to use of increasing simplicity of math formalism (Fig. 2).

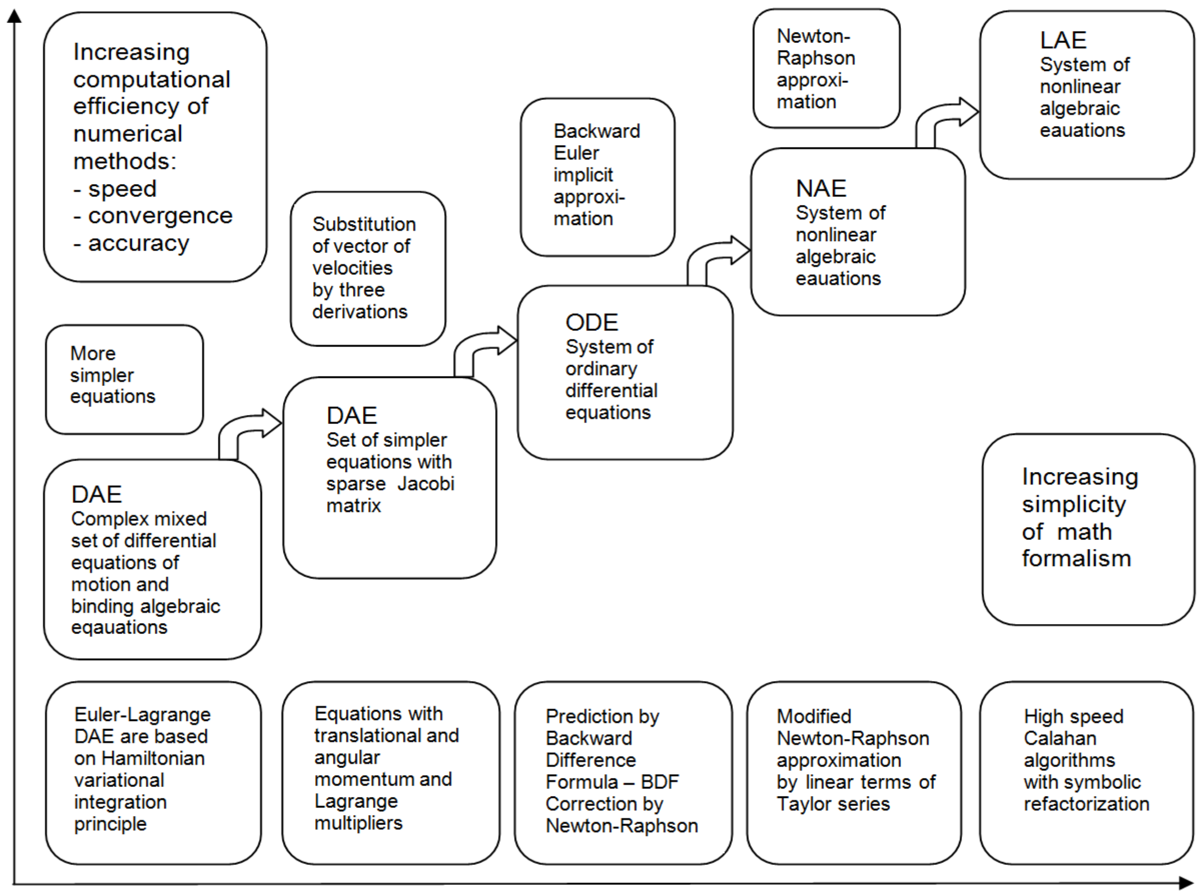


Fig. 2. The increasing computational efficiency and increasing simplicity of math formalism

3. Development of positioning mechanisms

The goal to increase seismic resistance of great variety of mechanisms requires discovering common properties and trends in development of these mechanisms. The number k of basic loops in structure of mechanism is probably the most important invariant property discovered by Euler (1707-1783). In the transition from immovable objects to the movable articulated chains with increasing number of actuators (mono-bi-poly) it can be recognized the Law of Dynamicity.

Table : The types of mechanisms according to their structure

Number k of basic loops	$k = 0$	$k = 1$	$k > 1$	$k = 0 + k > 0$
Type of mechanism	Open mechanism	Single loop mechanism	Many loops mechanism	Combined mechanism
The mark	OM	SLM	MLM	CM

A great variety of positioning mechanisms are used in machines and devices. Even though these applications are quite different, all mechanisms can be classified into three task categories depending on the mission that mechanisms perform: Path generation (positioning of output link LCS origin, Function generation (positioning of output link local coordination system-LCS axes), and Motion generation (positioning of output link LCS origin and axes, too. It is simultaneous combination of positioning of output link LCS origin and orientation of output link LCS), [5] (Erdman, Sandor, Kota, 2001).

In general the Cauchy-Poisson theory of decomposition of general spatial motion into translation represented by reference point and by spherical motion about this reference point can be used for explanation of mission of positioner located in inner ear as additional sense to the known five types of our senses (Fig. 3 a, b).

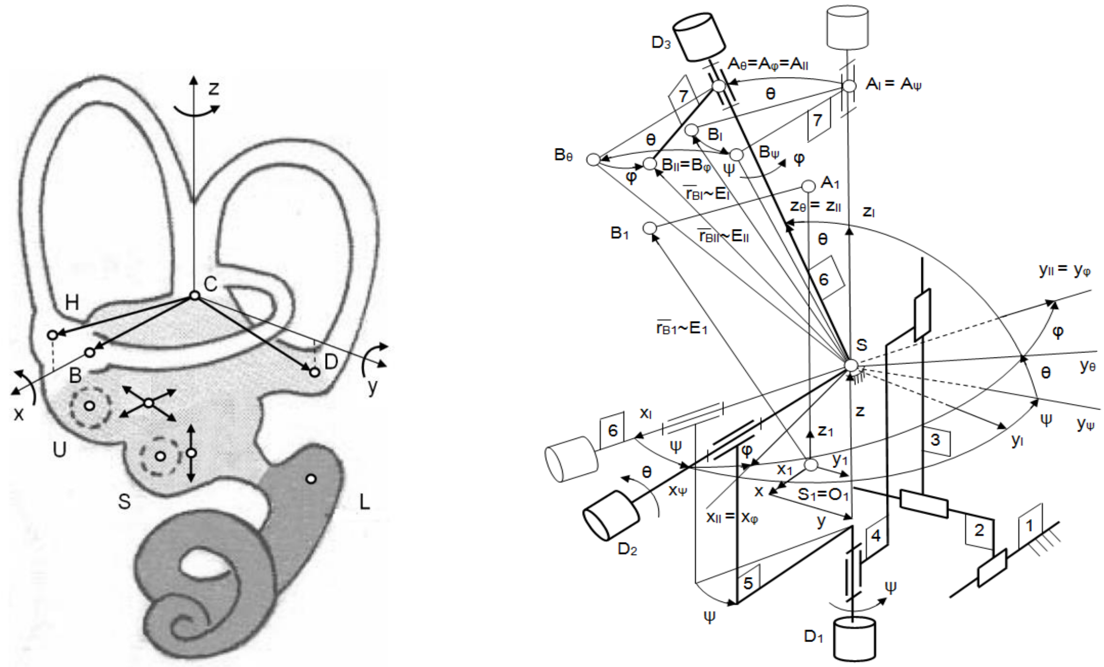


Fig. 3 a) The positioner with three semicircular ducts and extended ampoules H, B, D, upper ovate sac U (utriculus), round bottom bag S (saccus), b) open positioning mechanism with mobility n = 6

3.1 The positioning mechanisms with parallel structure

First positioning mechanisms in industrial robots were designed with articulated structures of the serial type (k = 0 in Tab.1). Their advantage was required dexterity and envelope however without acceptable accuracy and stiffness. On the other hand, parallel robots (k > 0 in Tab.1) like Tricept on Fig 4. [6] (Neuman, 1988), have structure with three or more prismatic and rotary axes which function parallel to one another. The robots with parallel architecture have increased stability and arm rigidity, with faster cycle times than serial robots.

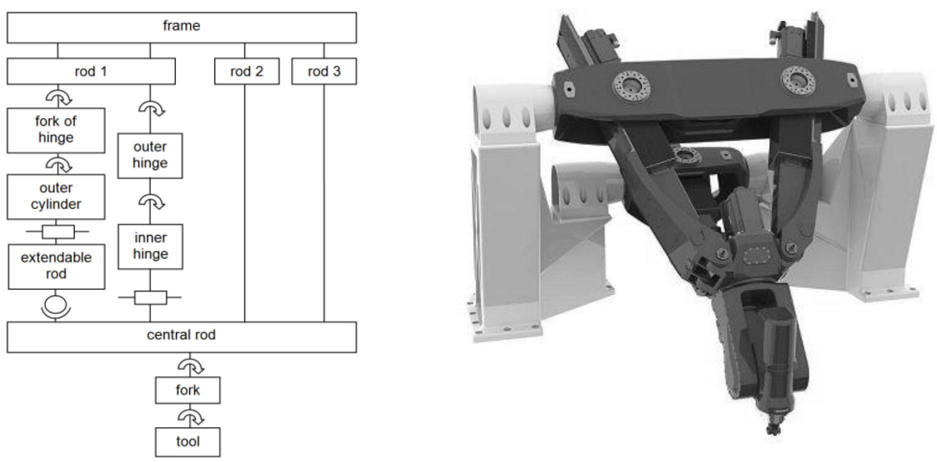


Fig. 4 a) scheme of structure of PKM machine Tricept b) the hybrid Exechon technology

Current development is focused on the redundantly actuated parallel structures like Sliding Star [7] (Valasek, Sika, Hamrle 2007), with mobility n = 3 DOF and 4 actuators can substantially improve all mechanical properties of machine. Such mechanisms achieve higher stiffness, eigenfrequencies and accelerations, their workspace is without singularities, ratio between workspace and machine overall space is improved, and modified control strategy removes drive conflicts. This is advantageous also from point of view of seismic resistance.

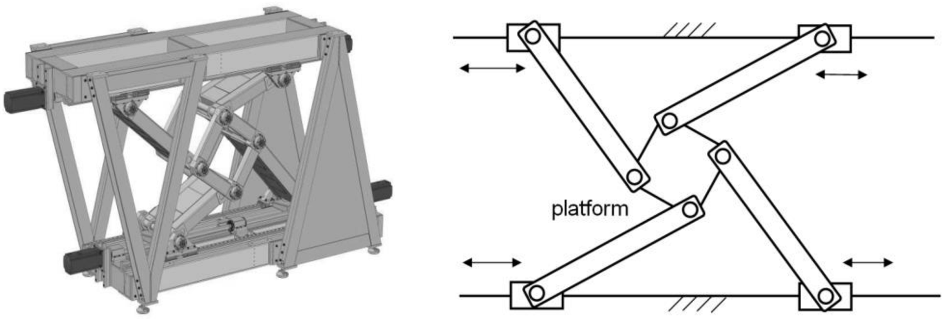


Fig. 5 a) redundantly actuated PKM machine Sliding Star b) kinematic scheme

3.2 The hand latch self-locking toggle mechanism

Looking to the list of TRIZ Standard solutions, the Evolution of systems (Class 2) is characterized by transition to a more flexible, rapidly changing structure of the system. As a suitable example is the hand latch self-locking toggle mechanism (U.S. Pat. No. 19660000337, 1966) invented by Holman, Earl V. (Whittier, CA) in order to meet the following design requirements:

- to securely clamp two halves of large shipping containers together by clamping force at least 800 N.

- Is hand-actuated by less than 80 N force and hand released with effort of 5 N force.

- Clamping remains secure under vibration (technological or seismic).

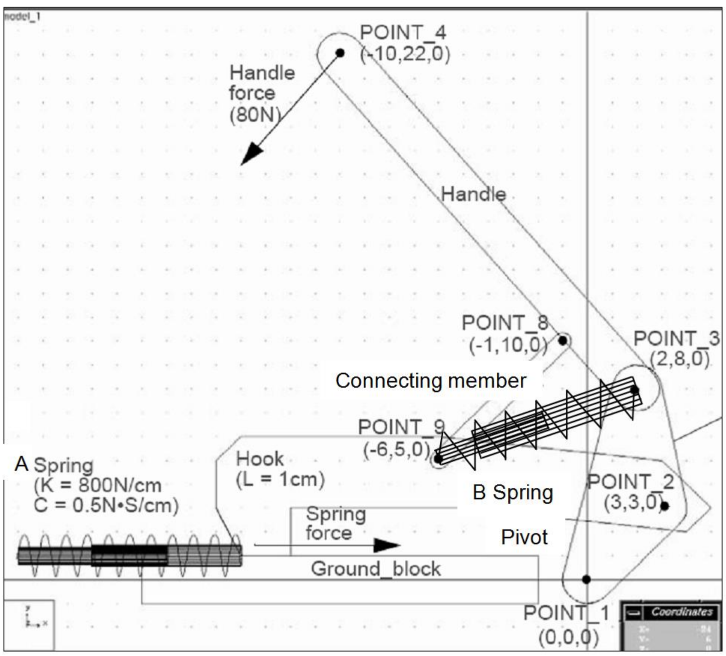


Fig. 6. The hand latch self-locking toggle mechanism

The latch is clamped by pushing down on the operating handle at POINT_4. This causes the pivot to rotate around POINT_1 in a clockwise direction, drawing back POINT_2 of the hook. As this happens, POINT_8 of the connecting member is forced downward. Finally, as POINT_8 passes through the line between POINT_9 and POINT_3, the clamping force (represented by force of A spring) reaches its maximum. When POINT_8 is moving below the line created by POINT_3 and POINT_9, due common action of forces in A spring and B spring the latch mechanism is toggled in locked configuration in which the operating handle is coming to rest on the top of the hook. This sets the latch near required maximum force point, but allows a reasonable release force to open the latch.

4. Application of AFD-TRIZ in research of seismic resistance

The mission of the energy entering the system is to ensure that the system fulfills its function. The system is subjected to the controlled working regimes (operational excitation) and noise (external excitation: seismic vibrations, temperature changes, humidity, ...). During transfer the useful portion of energy performs functions and the unwanted part (conversion to heat due chafing, as dynamic load causing the change the shape-deformation, to induce increasing oscillations-resonance, ...) is causing harshness the fulfillment of system functions which may cause system failure.

4.1 Mission of the method Anticipated Failure Determination

Boris Zlotin, who collaborated with Altshuller, author of TRIZ approach, came in 1978 with the idea that if we want to predict failure, first it is necessary to invent purposefully how cause a failure. This creative idea how to provoke-synthesize the damage the function of a device was the basis for method AFD-TRIZ (Anticipated Failure Determination), suggested in 1997 by Dr. Kaplan [8]. AFD-TRIZ is application of I-TRIZ to Risk Analysis as the Theory of Scenario Structuring which provides a thorough, broad and transparent approach with unifying structure whereby may be other methods (NVH, FMEA, and HAZOP) to understand and compare.

- Failure Analysis: AFD-1, uses AFD to finding the cause of a failure that has already occurred. In principle, Failure Analysis is the NVH (Noise, Vibration, and Harshness) analysis of the function failure.

- Failure Anticipation (prediction): AFD-2 is the application of AFD to identifying possible failures that have not yet occurred by inventing them.

- Failure Prevention: AFD-3 utilizes AFD to enable avert the cause of the failure, eliminate the failure, or stop the effects of the failure using TRIZ tools.

4.2. Development research *of seismic resistance of air flow regulator*

The elastic properties of the flow regulator on Fig.7 represent its modal content, so in the program ADAMS (Automated Dynamic Analysis of Mechanical Systems) acts as an superelement. The response is the result of the superposition principle of eigenmodes according to the Hurty-Craig-Bampton methodology.

For evaluation the results from simulations of seismic events the most used are courses of transfer functions (or spectra) in the frequency domain. These plots show us how frequency-sensitive is the system to the seismic excitation at a given location and direction.

When frequency of seismic excitation is same as eigenfrequency of equipment then these frequencies are conflicting properties. The goal to increase seismic resistance of equipment can be achieved by separation of conflicting properties in space of frequency domain (#1 from Separation Principles to resolving physical contradiction).

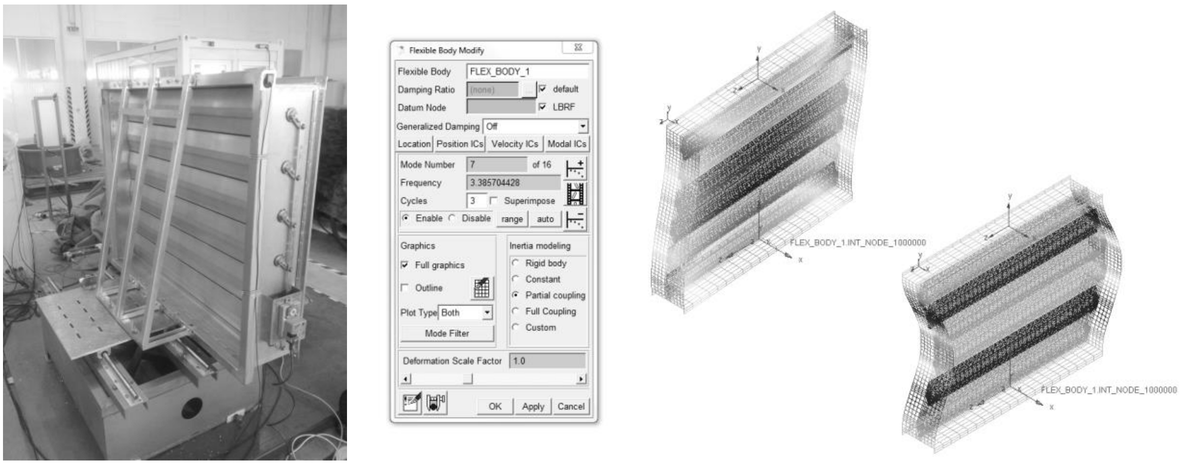


Fig. 7 a) real experiments of air flow regulator, b) eigenmodes in the ADAMS/Vibration.

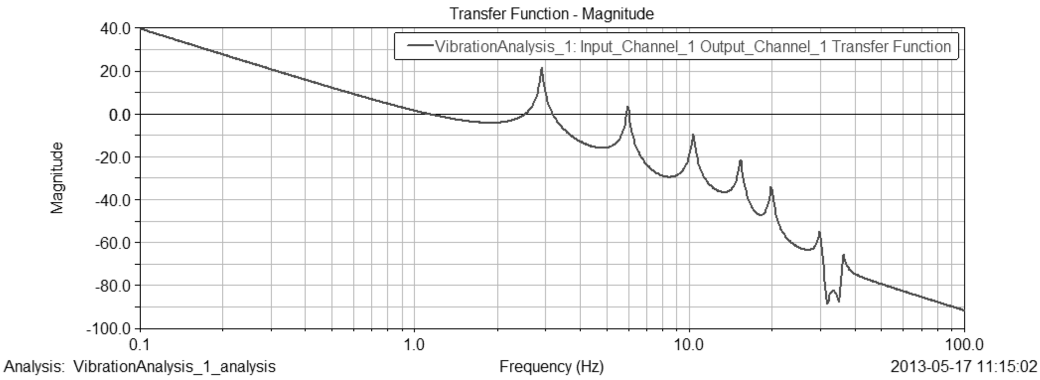


Fig. 8. The transfer function from input channel to the output channel.

While the seismic excitation cannot be changed, there is possibility for its passive, semi-active, or active damping using flexible connectors, adjustable hydromounts, without or with feedback. So it is possible:

- change in viscosity of magneto-rheological liquid in the hydromounts cause attenuation of influence of seismic excitation by its damping,
- change in mass or stiffness of equipment structure cause change of its eigenfrequency.

It corresponds with trend for stepwise elimination and final exclusion of human involvement from control process.

5. Conclusions

If we apply the laws of evolution of technical systems for synthesis of positioning mechanisms, we find that effort should focus on the transition from planar to dexterous spatial mechanisms that allow to achieve comparable outcomes with fewer elements, with fewer demands on the operating space during working regimes, as well with fewer inputs, which is advantageous in terms of production, assembly and maintenance but also from design of control system point of view.

Users will obtain the ability to make generalized analogy to compile baseline model, to think simultaneously from a point of view of thought (ontogenetically) and of the development of techniques (filogenetically), ability to work with statistical tools to detect a multidisciplinary context.

We all are looking for hidden reserves for further improving of ourselves and the world. Products that are more secure, efficient and environmentally friendly prove that a combination of real experiments with simulations have not said the last word. A much greater potential than upgrading existing things by prevailing methods of analysis mainly in one area of knowledge, have methods of synthesis with a systematic approach of creating new things using TRIZ approach.

The TRIZ approach combines meaningful thinking (dialectical logic), imagination (fantasy) and generalized experience of the inventors of the past with present instruments (importance of content of the words-semantics, organized thinking-ontology, self similarity-fractality, self improvement-extropianism,...).

The user of TRIZ approach is guided purposefully (systematic) and repeatable:

- from uncertainty in the definition to clear naming of the task (from distractions to unity),
- from description with many meanings to revealing the common nature of a design (from multiplicity to simplicity),
- from control (without feedback) to the self-regulation (from forcing to spontaneity).

In this paper we would like to point out that in addition to real and virtual experiments examining seismic is necessary to take into account the creative approach that helps overcome the psychological inertia when considering such an important area as the seismic safety of nuclear plants.

Acknowledgements

This paper was created by the implementation of the project "Improving the safety of nuclear installations during seismic events" (ITMS project code: 26220220171) on the basis of Operational Programme Research and Development financed by the European Regional Development Fund.

References

1. Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. Taxonomy of educational objectives: the classification of educational goals; Handbook I: Cognitive Domain, New York, Longmans, Green, 1956.

2. Altshuller, G. S.: 40 Principles: TRIZ Keys to Technical Innovation. Translated by Lev Shulyak, Technical Innovation Center, Worcester, MA., 1998.

3. Huynh, P., and Hervé, J.M.: Equivalent Kinematic Chains with Planar-Spherical Bonds Application to the Development of 3-DOF 3-RPS Parallel Mechanism. Proceedings RAAD'03, Cassino, 2003.

4. Orlandea, N., Chace, M.A., Calahan, D.A.: A Sparsity Oriented Approach to the Dynamic Analysis and Design of Mechanical Systems. Part I. and II. Journal of Engineering for Industry, Vol. 99. pp. 773-784, 1976.

5. Erdman, A. G., Sandor, G. N., Kota, S.: Mechanism Design, Analysis and synthesis, Prentice Hall, N.J., 2001.

6. Neuman, K. E.: Robot, US Patent 4732525, 1988.

7. Valasek, M., Sika, Z., Hamrle, V.: From dexterity to calibrability of parallel kinematical structures, 12th IFToMM World Congress, Besançon (France), 2007.

8. Kaplan, S., Visnepolshi, S., Zlotin, B., Zusman, A.: New Tools for Failure and Risk Analysis. Anticipatory Failure Determination (AFD) and the Theory of Scenario Structuring, Ideation International, pp.71, 2005.

Author (co-author) to contact: Frantisek Palcak, frantisek.palcak@stuba.sk

TRIZfest 2014

Application of TRIZ in Rapid Switching Temperature of Semiconductor Test Apparatus

Jung-Hyeon Kim[a*], Jun-Young Lee[a], Vladimir Urazaev[b]

[a]*VIPCenter, Samsung Electronics, Republic of Korea*

[b]*Former Employee in Samsung Electronics, Republic of Korea*

Abstract

TRIZ methodology has been intensively used to solve problems at a lot of industrial companies. Samsung Electronics is one of those companies to use TRIZ and has lots of achievements in various fields.

This paper shows the application related to the semiconductor test apparatus. Semiconductor chips are used in very severe environments, especially in hot and cold conditions. In order to satisfy such severe conditions, hot and cold tests are carried out for each chip before outgoing to customer.

The test apparatus should be possible to raise or lower the temperature in the test chamber for common use of both tests. However, it took very long time to raise or lower the temperature, which means that the productivity was extremely low due to poor utilization efficiency of test apparatus. In this paper, the practical application of TRIZ to reduce the transition time is described.

Keywords: TRIZ, semiconductor test apparatus, hot/cold test

1. Introduction

In digital era, we are facing severe competition and rapid change, and it is believed that prior occupation of core technologies is a key for surviving in business fields under these circumstances. The company without core technologies cannot lead the world and the bright future cannot be guaranteed in 21 century. Thus TRIZ can be a good methodology for the companies that need effective approach for innovation and invention.

Since TRIZ was introduced to Samsung Electronics in 1998, TRIZ methodology has contributed to various fields of Samsung products and manufacturing processes including mobile phones, semiconductors and home appliances (televisions, refrigerators, air-conditioners, etc.)

This paper shows the application related to the semiconductor test apparatus. Semiconductor chips are used in very severe environments, especially in hot and cold conditions. In order to satisfy such severe conditions, hot and cold tests are carried out for each chip before outgoing to customer.

In this paper, the practical application of TRIZ for reducing the transition time is described.

2. Initial Situation and Problem Statement

The test apparatus is called “test handler”, and it is divided into three following chambers: soak, test and exit chambers. Each device (molded chip) is placed into the soak chamber first and then moved to the test chamber where hot and cold tests are carried out. The device that is completed all tests finally moves to the exit chamber. Usually 512 devices are tested at the same time in order to maintain high productivity of apparatus.

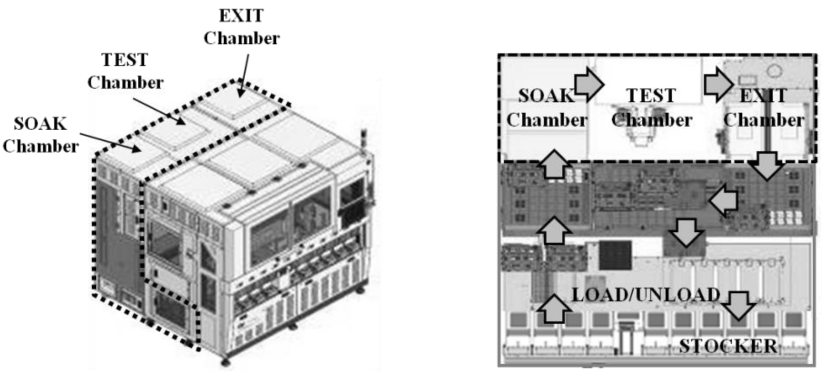


Fig. 1. Test handler (Iso & Top View)

In general, hot and cold tests were carried out in standard condition of high temperature and low temperature (below zero), respectively. Air was heated by heater and circulated by fan during the hot test, meanwhile, liquid nitrogen (LN2) was used to cool air blowing during the cold test. In order to raise or lower temperature of the device, it had to be exposed to hot or cold air for long time (about 60min) in test chamber.

Table 1. Specifications of apparatus for temperature changeover

Condition	Time
Cold → Hot	About 60 min
Hot → Cold	About 60 min

The test apparatus should be able to raise and lower temperature in the test chamber for common use of both hot and cold tests. However, it took very long time to raise or lower temperature, so it was hard to proceed with two tests sequentially.

Therefore each apparatus should be separated into hot and cold test exclusively to enhance the utilization efficiency, which means that the device completed the hot test move to another apparatus manually to carry out the cold test. The productivity, of course, was extremely low due to poor utilization efficiency of test apparatus.

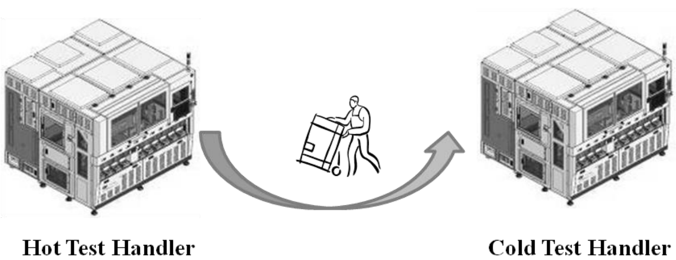


Fig. 2. Old method utilizing test handlers

Moreover the size of test chamber likely to be large depending on increase of amount of devices tested simultaneously, which means that more time to change temperature has to be needed.

3. Approaches to Solve the Problem

3.1. Definition of the problem

The goal of this project was to reduce time for temperature changeover from about 60 minutes to at least 1 minute or less, it was no more challengeable than that.

Condition	Time	Goal
Cold → Hot	About 60 min	At least 1 min
Hot → Cold	About 60 min	At least 1 min

Fig. 3. The goal of task

3.2. Function Analysis

Function modeling shown of Fig.4 was used to find each function of components composing the system and their relationship. First, the devices holding by insert are entered into test chamber from soak chamber, and then pushers press those to contact into the socket connecting with tester electrically. In this state, the devices are exposed to hot/cold air during full process.

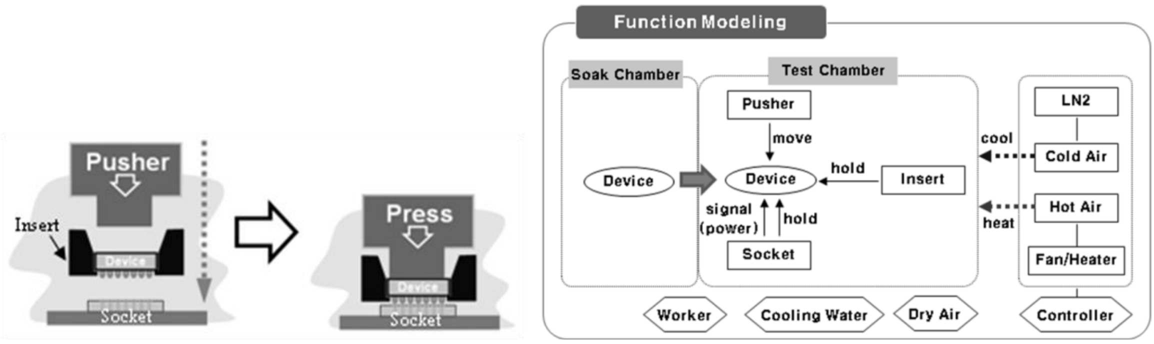


Fig. 4. Function modeling

It is possible to know that forced convection heat transfer is occurred in test chamber, and it is described as below Newton's equation.

$$q = hA(T_s - T_\infty) \qquad (1)$$

In order to increase the efficiency of convection heat transfer, two approaches are considered generally. First, it is suggested to increase *h*(heat transfer rate) by enhancing the performance of pump or fan. Second, it is suggested to increase *A*(area) of the object.

So detail resource analysis was carried out to find out possibilities to modify fan or other components. However, all of suggestions could not be adopted in our project owing to several structural constraints.

Therefore, we had to change fundamental method for heat transfer in our system; conduction type was considered as an alternative. Heat conduction equation is described as below Fourier equation.

$$q = -kA\frac{\partial T}{\partial x} \qquad (2)$$

From the performed function analysis, we could find out basic interactions between components, especially we paid attention to pusher that had a direct interaction with the device. Based on that, at 1st step, we tried to use Peltier element utilizing thermoelectric effect (peltier effect) that is the presence of heating or cooling at an electrified junction of two different conductors. From the engineering point of view, the usefulness of Peltier device was clear and it could be the simplest way theoretically.

However, the results were very good in case of raising the temperature, on the contrary, were not enough in case of lowering the temperature. In addition, there were some problems of cost and manufacturing in small size.

3.3. Contradiction Analysis

Contradictions could be analyzed intuitively based on previous analysis. It is possible to enhance heat transfer (positive effect) by using conduction method, on the other hand it is possible to test large amounts of device simultaneously and change small design of current system (positive effects) by using convection type. In addition to, as we mentioned for Peltier element, heat transfer rate of conduction was good in the case of heating, but it was not enough in the case of cooling. Therefore we tried to consider two types of heat transfer together in same system. How could be each advantage of two types of heat transfer mechanisms combined together?

In order to dig deeper into the problem being solved, process analysis was performed. As mentioned above, there were three major process steps (soak, test and exit). From the process analysis, we reset up the test process to implement our concept, i.e. it was recommended to do cold test before hot test.

For this, when the devices were waiting in soak chamber, it was suggested to pre-cool the device. Therefore, during the time for waiting in soak chamber, the devices were exposed to air below zero. Already cooled devices were entered into the test chamber where the temperature was also below zero.

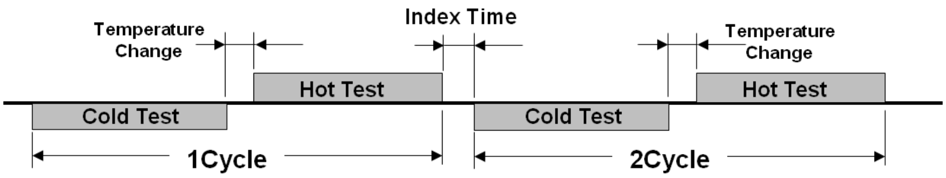


Fig. 5. Arrangement of test process

According to the approach of separation in system level, internal temperature of the whole test chamber was maintained under specific temperature below zero, and the device was heated by a specific heater attached to the pusher locally.

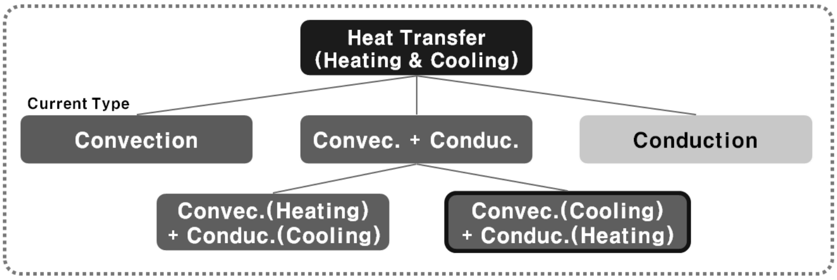


Fig. 6. Directions of solution

This situation can be expressed metaphorically as blow. CAE simulation was conducted to define the theoretical feasibility of our concept, and we obtained satisfactory results of modeling.

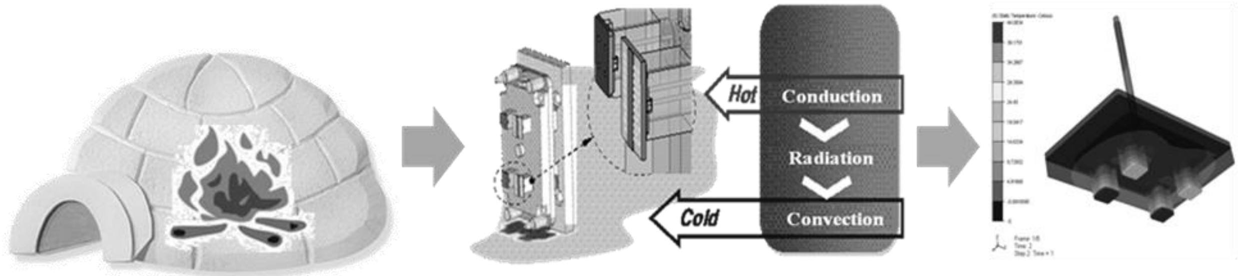


Fig. 7. Schematic Concept and CAE results

3.4 Verification of Concepts

Based on the above analysis, we needed to find heaters that could be implemented within the actual apparatus. How to raise temperature of device rapidly in the local area? FOS assisted patent analysis was conducted and leading areas were identified through IPC analysis. Several heaters were suggested: posister heater, micro peltier, IR heater, heat pipe, cartridge heater, etc. Then, various tests were performed to investigate compatibility with the existing system requirements. Finally, IR heater and cartridge heater were selected and evaluated under actual conditions. The heater should be made in very small size to be installed into the real apparatus.

In case of IR heater, it could be manufactured in small and thin film type which allowed good results in both cases of raising and lowering temperature of the device. However, there were some problems associated with low controllability of temperature and productivity of the heater.

Meanwhile, cartridge heater was manufactured in the shape of round bar and considered to have enough power to enable rapid heating. It had an advantage of high durability and easy productivity. Test results showed that it took within 1 minute to raise the temperature and more than 1 minute to lower the temperature. In spite of small size, the speed of lowering temperature had nearly doubled more than that of raising temperature. The additional analysis was performed to understand this phenomenon.

As a result of analysis, after hot test, test-finished devices were moved to the exit chamber from test chamber, and then new devices were entered into the test chamber. As soon as the hot test was completed, power of heater turned off automatically. However, when the pusher pressed the new device, the pusher was still hot because of latent heat. As a result, the new device cooled below zero in soak chamber was hot again. To carry out cold test, the pusher should be cool rapidly.

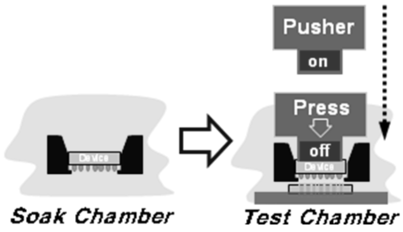


Fig. 8. Situation of secondary problem

Therefore, to solve this new problem, available resources were investigated in more detail. Above all, through modification of design, the volume of heater was reduced to drop down the latent heat of cartridge heater.

And then we suggested to cool the device in soak chamber at lower temperature, which could reduce the rise of temperature of the device pressed by hot pusher. In addition to that, cooling air around pusher in chamber was actively used. Dry air was cool down during passed through chiller using LN2, and then it was blown to the contact surface between pusher and device through hole inside the pusher.

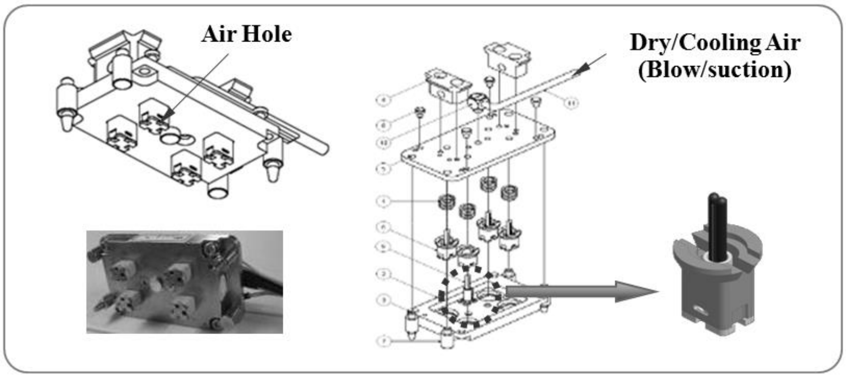


Fig. 9. Mini cartridge heater

3.5 Implementation of Solutions. Final Results

The above mentioned solution was tested in real apparatus, and we could achieve very successful results in both hot and cold tests. Test results showed that it took within 1 minute to raise or low the temperature. Based on that, it was possible to use commonly just one apparatus for both hot and cold tests.

Table 2. Test results of temperature changeover

Condition	Problem Situation	Test Results
Cold → Hot	About 60 min	Within 1 min
Hot → Cold	About 60 min	Within 1 min

4. Conclusions

This paper shows the application related to the semiconductor test apparatus. Semiconductor chips are used in very severe environments, especially in hot and cold conditions. In order to satisfy such severe conditions, hot and cold tests are carried out for each chip before outgoing to customer.

The test apparatus should be possible to raise or lower the temperature in the test chamber for common use of both tests. However, it took very long time to raise or lower the temperature, which means that the productivity was extremely low due to poor utilization efficiency of test apparatus.

Consequently, it was demonstrated how analytical tools of TRIZ were used to identify the problem responsible for low productivity of the apparatus for testing semiconductor devices. Then, the conceptual solutions for the problem were developed with the help of TRIZ problem solving tools including FOS and resolving contradictions.

Based on that, actual implemental steps were carried out to concrete various concepts. In conclusion, final results showed significant improvement of transition time.

References

1. Altsthuller, G. Creativity as an exact science. Gordon and Breach Scientific Publishers, 1984.

2. Jack P. Holman. Heat Transfer, 9th Edition. McGraw-Hill, 2001.

3. Adrian Bejan. Convection Heat Transfer, 3rd Edition. John Wiley & Sons Inc, 2003.

4. Jong-won Han, Jung-Hyeon Kim. “Test socket, apparatus for testing an object having the test socket, and method of testing an object using the apparatus” South Korea Patent, 10-2010-0004451, Jan 18, 2010.

Author (co-author) to contact: Jung-Hyeon Kim, todd.kim@samsung.com

TRIZfest 2014

Applying Consecutive Hybridization Approach for Mask Manufacturing (Case study is based on US 20130071775 A1))

Valeriy Prushinskiy[a], MinSoo Kim[b]

[a]*Samsung Display Company Ltd.,Yongin-City ,446-711, Republic of Korea*

[b]*Samsung Display Company Ltd.,Yongin-City ,446-711, Republic of Korea*

Abstract

This article describes practice of multi-step hybridization for resolution of complex inventive problems. Applying inventive principle "Combining" for increasing of ideality of engineering systems was proposed and carefully described by Genrich Altshuller. Later, algorithm of Feature Transfer was proposed by Vladimir Gerasimov and Simon Litvin. Feature Transfer is an analytical tool for improvement of base engineering system by transferring relevant features from the alternative system. In case of complex problem, it is very difficult to resolve contradictions by single-step combining or feature transfer. That is why multi-step approach for consecutive hybridization was developed. Authors discuss details of application of this approach as hybridizing of several non-alternative systems for development of high resolution mask resulted in concepts proposed in USA patent application US 20130071775 A1.

Keywords: algorithm of consecutive hybridization of multiple systems, hybridization, OLED.

1. Introduction

Applying inventive principle "Combining" for increasing of ideality of engineering systems was proposed and carefully described by Genrich Altshuller in 1969 [1] as inventive principle, suggesting to combine or merge identical or related objects, operations or functions. Later, he described mono-bi-poly trend, according to which at some point, technical systems evolve via combining with another ones into bi-systems, then tri-systems and next – poly-systems [2]. In classical TRIZ this line is known for combining of similar engineering systems and different engineering systems. Opportunity to combine systems for obtaining more efficient concepts attracted a lot of attention of TRIZ-developers in 1980s. Thus, Boris Zlotin and Alla Zusman proposed their recommendations for combining "bi-systems with biased characteristics" [3]. Later, Vladimir Gerasimov and Simon Litvin were first to propose remarkably efficient algorithm of Feature Transfer [4]. Feature Transfer is an analytical tool for improvement of base engineering system by transferring relevant features from the alternative system.

2. Feature Transfer Algorithm

Vladimir Gerasimov and Simon Litvin have defined their algorithm of feature transfer as set of following steps:

1. Identify main function of the system/component

2. Formulate key advantages and disadvantages in form of a contradiction

3. Identify competing systems

4. Select alternative engineering system

5. Select base engineering system

6. Formulate feature transfer problem

Feature was described as characteristic of an alternative engineering system to be transferred to the base engineering system to eliminate disadvantage of the base system. During feature transfer process one of the alternative systems was selected as basic system. Usually, it was recommended to select system which is simpler and less expensive as basic one. Goal of this algorithm is to obtain solutions, where the advantages of two alternative systems are integrated, and disadvantages are eliminated. But in reality, it is not so easy to eliminate disadvantages, and also, new unexpected disadvantages can appear as result of feature transfer. Also, there was a need in recommendations and algorithms for combining of non-alternative systems, because Feature Transfer Algorithm is focused on limited class of the systems - alternative systems are systems with same main functions, but opposite advantages and disadvantages.

2. Algorithm of Consecutive Hybridization of Multiple Systems

The algorithm of consecutive hybridization enabled crossing of as many systems as required [5]. Also, the algorithm helps in combining different engineering systems, both alternative and non-alternative. Here is brief description of the algorithm steps:

1. Identify initial engineering system (describe as a set of simple ideas with list of advantages and disadvantages)

2. Describe candidate for crossing (describe as a set of simple ideas with list of advantages and disadvantages)

3. Describe hybridization contradiction

4. Select dominant engineering system

5. Reveal resources for hybridization

6. Describe portrait of hybrid

7. Formulate ideal vision of hybridization problem

8. Reveal resources of dominant engineering system

9. Describe intermediate hybrid

10. Reveal drawbacks, not addressed by intermediate hybrid

11. Select next engineering system for hybridization

12. Repeat hybridization process

Consecutive hybridization process will be briefly explained below based on concepts described in US 20130071775 A1. In this process three non-alternative systems were used for multi-step consecutive hybridization: mask (main function: define pattern on the glass), evaporation chamber (main function: deposit organic material into pixel area), existing mask manufacturing process (main function: produce openings in metal sheet).

Currently, most OLED display products use shadow mask for colour patterning [6]. Simply speaking, that means that organic material is heated and evaporated from crucible (fig. 1), then molecules of evaporated materials fly through the openings (apertures) of the mask and reside on the glass (substrate).

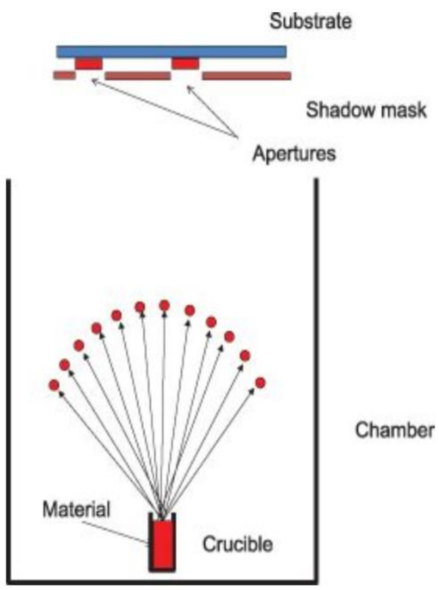


Fig. 1. OLED manufacturing [Source: OLED Display Fundamentals and Applications. Takatoshi Tsujimura. Wiley; 1st edition, ISBN-10: 1118140516, 256 pages]

Criteria for optimal patterning include high accuracy, low thermal expansion and minimal shadowing effect (unintended excessive shadowing due to high-incident-angle incident molecules relative to the normal angle, which are prevented from reaching the substrate).

To reduce the shadowing effect, use of a thin shadow mask with tapered shape (fig. 2) in its aperture provides an effective method.

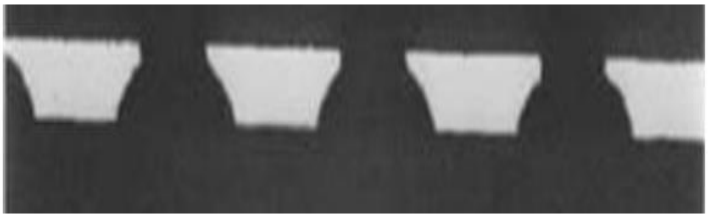


Fig. 2. Cross-sectional view of a shadow mask. [Source: OLED Display Fundamentals and Applications. Takatoshi Tsujimura. Wiley; 1st edition, ISBN-10: 1118140516, 256 pages]

Recently, in order to meet the technical requirements for a high-density semiconductor device or a high-resolution flat panel display, a deposition mask or a photomask capable of depositing or transferring high-resolution patterns onto the substrate has been required [7]. That means that size of the mask rib is continuously decreased every year due to the resolution growth. If more pixels have to be placed on square inch, cross section of the masks' rib has to be reduced. At some point, the mask's rib became so small, that it loses its strength. In this case, the ribs are "twisting", i.e. distance between the ribs became non-uniform. In some places of the mask ribs are too close to each other, in other places they are located too far. In these cases, after evaporation of organic material and its deposition on glass, it results in too big or too small pixels and too big shadows, when materials from neighbouring pixels are mixed. Here is step-by-step explanation of applying consecutive hybridization algorithm:

Step 1. Identify initial engineering system (describe as a set of simple ideas with list of advantages and disadvantages)

Existing Mask#1 with "big" ribs

+ The ribs are not bending and keep required shape

- Dimensions of the rib are too wide, so that there is no enough space for pixels

Step 2. Describe candidate for crossing (describe as a set of simple ideas with list of advantages and disadvantages)

Mask#2 with "small" ribs

+ Dimensions of the rib is small, so that there is enough space for more pixels

- Ribs are bending and cannot keep required shape, because bottom part of the rib is disappearing during manufacturing

Step 3. Describe hybridization contradiction

New hybrid mask has to be like Mask#1, so that it will have "big" ribs" that would not bent, and hybrid mask has to be like Mask#2, so that it will have "small" ribs, so that it will provide required space for smaller pixels.

Step 4. Select dominant engineering system

We select Mask#1, because we can produce it without bent ribs.

Step 5. Reveal resources for hybridization

Thin ribs of the Mask#2.

Step 6. Describe portrait of hybrid

Hybrid with "big" ribs, where there are "small" ribs.

Step 7. Formulate ideal vision of hybridization problem

Hybrid Mask#1 with minimal modifications should accommodate features of Mask#2.

Step 8. Reveal resources of dominant engineering system

Wide and strong ribs.

Step 9. Describe intermediate hybrid

Mask with hybrid ribs that will be strong enough to prevent bending: wide-and-narrow ribs.

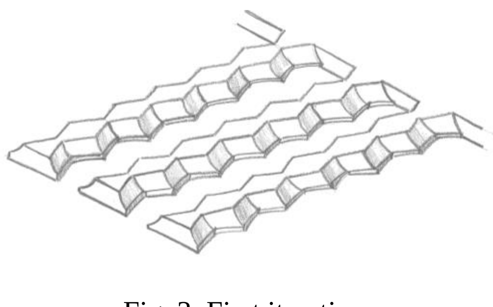


Fig. 3. First iteration.

Step 10. Reveal drawbacks, not addressed by intermediate hybrid

Intermediate hybrid concept was generated very straightforward, as ribs with small and big cross-sections one after another, providing strong ribs (fig. 3). But, drawback is non-uniform edges of the pixels, that is why this concept cannot be accepted.

Step 11. Select next engineering system for hybridization

Due to drawbacks of the initial concept, additional resources have to be revealed for second iteration of hybridization. OLED display manufacturing chamber was considered as one of the candidates for follow-up hybridization. It was revealed, that after evaporation, evaporated organic material in the central part of the mask is passing through the mask nearly without any inclination angle. On the edges of the mask (right and left sides), inclination angle value far from optimal straight angle.

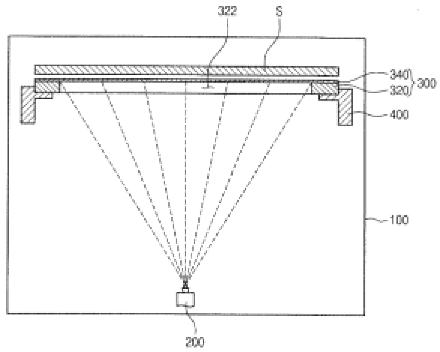


Fig. 4. Evaporation chamber.

Step 12. Repeat hybridization process

Now we continue hybridization, and use concept of the first intermediate hybrid for further hybridization.

Second Iteration

Step 2-1. Identify initial engineering system (describe as a set of simple ideas with list of advantages and disadvantages)

Mask with hybrid ribs that will be strong enough to prevent bending: wide-and-narrow ribs.

+Ribs would not bent

- Difficult manufacturing

-Uneven edges of pixels are unacceptable for production

Step 2-2. Describe candidate for crossing (describe as a set of simple ideas with list of advantages and disadvantages)

Mask with "specialized" ribs accommodated for evaporation in central part and on the edges (left and right parts).

Step 2-3. Describe hybridization contradiction

New hybrid mask should be like mask with wide-and-narrow ribs, and it should be as "specialized" mask accommodating different conditions of evaporation.

Step 2-4. Select dominant engineering system

"Specialized" mask selected dominant system as simpler one.

Step 2-5. Reveal resources for hybridization

Ribs with "wide" base, accommodating evaporation on the left and right sides.

Step 2-6. Describe portrait of hybrid

Mask with expanded "widened" base and ribs, depending of its position on the mask.

Step 2-7. Formulate ideal vision of hybridization problem

Hybrid Mask#3 with minimal modifications should accommodate features of concept of Intermediate Hybrid Mask.

Step 2-8. Reveal resources of dominant engineering system

Wider base part of the ribs on the edges, and wider "tail" part of the ribs in central part.

Step 2-9. Describe intermediate hybrid

Mask#3 should be asymmetric with expanded base part in the left part and in right part. Also, in central part the bottom part of the ribs can be expanded. These modifications would make the mask stronger and prevent bending.

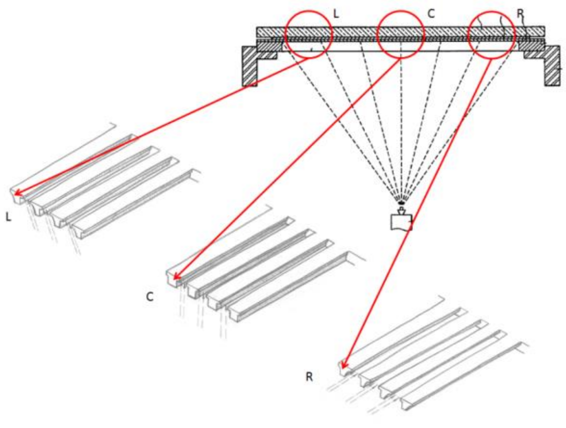


Fig. 5. New intermediate hybrid concept.

Step 2-10. Reveal drawbacks, not addressed by intermediate hybrid

In areas between the central part and edges the ribs still will be too thin, so bending and waving is possible in these zones. Concept of Mask#3 will require too many mask sticks, which have to have "special" shape in "special" place, so manufacturing is more complex.

Step 2-11. Select next engineering system for hybridization

Current mask manufacturing process was studied as next candidate for hybridization. Existing mask manufacturing process is schematically illustrated by following steps (fig. 6):

1. Patterning mask substrate (usually metal sheet) by forming first photoresist pattern on a top surface of the mask substrate

2. Forming a second photoresist pattern on a bottom surface of the mask

3. Etching mask to form first recess

4. Forming a third photoresist pattern to cover the first photoresist pattern and the first recess

5. Etching the mask substrate using the second photoresist pattern to form sidewalls of the ribs.

6. Stripping of photoresist and obtaining mask.

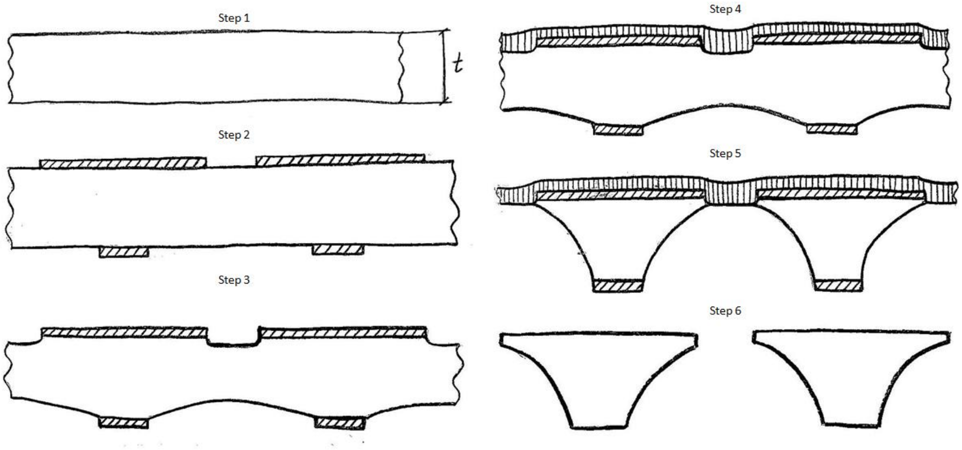


Fig. 6. Existing mask manufacturing process.

Step 2-12. Repeat hybridization process

Now we continue hybridization, and use concept of the second intermediate hybrid Mask#3 for further hybridization.

Third Iteration

Step 3-1. Identify initial engineering system (describe as a set of simple ideas with list of advantages and disadvantages)

Intermediate hybrid concept of Mask#3

- asymmetric ribs are stronger and prevent bending

- Individual sticks increase complexity of manufacturing

Step 3-2. Describe candidate for crossing (describe as a set of simple ideas with list of advantages and disadvantages)

Existing Mask, manufactured in 6 steps, as it was described above.

Advantage of this mainstream manufacturing process is reliability, but at if this approach will be applied for manufacturing the mask with fine high-resolution pattern, the bottom edge portion of the rib will be too small. For example, linear sidewalls 354b, 354d and 354'b ,354'd may disappear during etching, and final ribs may have a reduced rigidity, and may be deformed or distorted (fig. 7). This may result in a pattern failure of the mask.

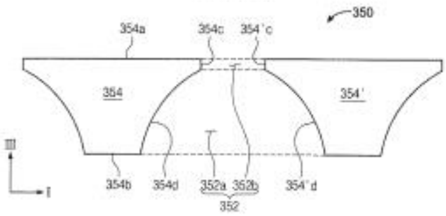


Fig. 7. High resolution pattern problem.

Step 3-3. Describe hybridization contradiction

New hybrid Mask should have features of Mask#3 preventing bending, and should have features of manufacturing steps, described above.

Step 3-4. Select dominant engineering system

Intermediate hybrid Mask#3.

Step 3-5. Reveal resources for hybridization

- expanded base part in the left part and in right part of the mask

- expanded bottom part of the ribs in central part

Step 3-6. Describe portrait of hybrid

New Hybrid Mask during manufacturing process should have expanded base in left and right sides.

Step 3-7. Formulate ideal vision of hybridization problem

New hybrid mask should use existing manufacturing process with minimal changes.

Step 3-8. Reveal resources of dominant engineering system

Wide base of the rib, expanded bottom portion of the rib.

Step 3-9. Describe intermediate hybrid

In order to use advantages of the current manufacturing technology, it was proposed to produce mask with "oversized" ribs wide base and top part, and then apply additional patterning to remove excessive material and make ribs smaller. Final concept of proposed technology will have following steps (fig. 7):

1. Patterning mask substrate (usually metal sheet) by forming first photoresist pattern on a top surface of the mask substrate, where first photoresist pattern having a top width greater that those of the final ribs

2. Forming a second photoresist pattern on a bottom surface of the mask

3. Etching mask to form first recess

4. Forming a third photoresist pattern to cover the first photoresist pattern and the first recess

5. Etching the mask substrate using the second photoresist pattern to form sidewalls of the ribs

6. Forming photoresist pattern having width substantially equivalent to the top widths of the final ribs and facing the bottom photoresist pattern

7. Etching the upper edge portions of the initial ribs using the upper and bottom photoresist patterns as etching masks

8. Stripping of photoresist and obtaining mask.

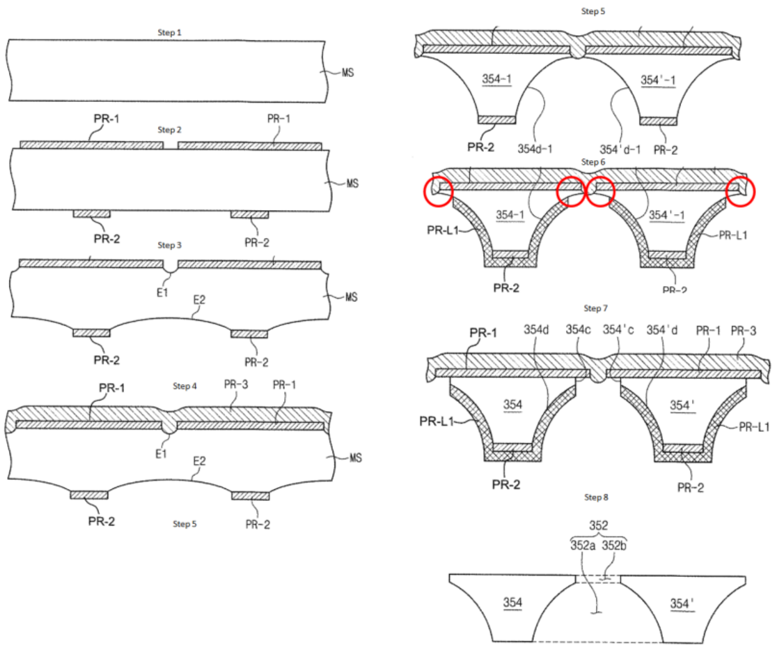


Fig. 7. Final concept.

Step 3-10. Reveal drawbacks, not addressed by intermediate hybrid

Although the number of manufacturing steps was increased, manufacturing of high resolution mask is possible in framework of current manufacturing paradigm. Several manufacturing alternatives were proposed based on the same concept.

2. Conclusion and Future Trends

As has been discussed, the mask manufacturing process improved significantly through systematic innovations by applying consecutive hybridization using advantages of different engineering systems and technologies. Note, if you are out of design alternatives, consider manufacturing process for several parts of engineering system and final product production process for selection of candidates for further hybridization. New competitive advantage was achieved by selecting good candidates for hybridization process.

Consecutive hybridization can play key role in modern innovation processes. It should be noted that currently lifetime of the electronic consumer products is continuously reduced, so that number of the candidates available for hybridization is dramatically increased. This will enable development of more detail approaches and recommendations for multistep hybridization, providing solution for new disruptive technologies and products. This thinking approach can drive companies for better and more systematic innovations, defining advantages that important for consumers.

References

1. Genrich Altshuller. Innovation Algorithm: TRIZ, systematic innovation and technical creativity. Genrich Altshuller. ISBN-13: 978-0964074040

2. Genrich Altshuller. To find the Idea. Найти идею. Генрих Альтшуллер. ISBN 978-5-9614-1794-4

3. Innovation Work Bench Software (by Ideation International Inc.)

4. V.M.Gerasimov and S.S.Litvin, Why Technology Needs Pluralism? Development of Alternative Technical Systems by Their Combining into Supersystem. Герасимов В.М., Литвин С.С. Зачем технике плюрализм: развитие альтернативных технических систем путем их объединения в надсистему. // Журнал ТРИЗ. – 1990. – Т.1. – № 1.

5. Val Prushinskiy, Gafur Zainiev, Vladimir Gerasimov. HYBRIDIZATION, The New Warfare in the Battle for the Market. ISBN 1-59872-069-4

6. Takatoshi Tsujimura. OLED Display Fundamentals and Applications. Wiley; 1st edition, ISBN-10: 1118140516, 256 pages

7. US Patent Application 20130071775 A1

Author (co-author) to contact: Valeriy Prushinskiy, p.valeriy@samsung.com

TRIZfest-2014

Applying TRIZ on a Biz Model

Lorenz Buchler*, Claudia Hentschel*, Oliver Mayer**

**HTW Berlin, Innovations- und Technologiemanagement, Produktentstehung und Betriebsorganisation, 10318 Berlin, Germany*
***Oliver Mayer, Kössenerstr. 6b, 81373 München, Germany , mayer@ibom.de*

Abstract

The tools that accompany the Theory of Inventive Problem Solving (TRIZ) originally revolve around improving or redesigning physical entities. These tools rely on the abstraction of the problem at hand. This paper showcases how selective TRIZ tools can be applied to the improvement of a particular business process.

After the application of six TRIZ tools to a business process, it is tested if it is possible to suggest specific non-technical improvements using TRIZ. Furthermore, there seems to be no reason why the extrapolation to an arbitrary business process should not be possible.

Keywords: Business model, Flow optimization, TRIZ, Six Sigma

1. Today's situation

Legions of advisors keep showing that there is a need of advice in companies. One reads of restructuring or reorganization of businesses. Keywords like Lean or Six Sigma are steadily mentioned. Why don't you ever hear about TRIZ?

With this paper the authors wanted to understand the effort of applying TRIZ to a business case. They were explicitly neglecting the fact that research has already been made in that area in order to gain knowledge and experience on the effort needed, to be able to transport this experience to the company management. In order to better be able to estimate the challenges and obstacles of expanding TRIZ from a technical training to an administrative application (although not quantifiable) this experience had to be made on their own.

2. Limits of an intuitive development of ideas

For solving problems, creativity is needed. Also people who describe themselves as non-creative, are creative because creativity is a natural ability (Koltze & Souchkov, 2011). Studies show that the natural human creativity declines with age (Kim, 2011). It is important to state that creativity does not disappear, but is replaced with experience. Studies prove that both creativity and the ability to think reflectively have decreased over the last decades (Kim, 2011). There are three different kinds of creativity barriers: Perception barriers, emotional barriers and barriers of the environment.

The first mentioned barriers are in the broadest sense perception problems. Emotional hindrances for example are culture, tradition, or social boundaries, lack of courage, or missing combat readiness. Environment barriers arise from the workplace, the company or from performance pressure, and routine (Koltze & Souchkov, 2011).

Creativity techniques work against the rising barriers and hence the decreasing natural creativity and at the same time stimulate new thoughts. Intuitive methods shall appeal to the subconscious and help to leave beaten paths, such as brainstorming or the method 6-3-5 (Koltze & Souchkov, 2011). However, the user will usually remain within his barriers. Furthermore, all intuitive approaches deliberately aim „in all directions“. TRIZ tries to control the process from the beginning (Hentschel, Gundlach & Nähler, 2010) without interfering with creativity.

The solution finder doesn't necessarily steer to the ideal solution. TRIZ tools like the ideality are directing from the outset to the best solution. They get the user to leave his traditional "comfort zone" in the search for a solution and to overcome his creativity barriers.

3. Selected TRIZ tools

The tool "ideality" opens the eyes for new approaches without having to penetrate the considered problem completely. The "function analysis" is performed because it is crucial for the understanding of the process. Together with the "resource analysis" it serves towards the necessary understanding of the process.

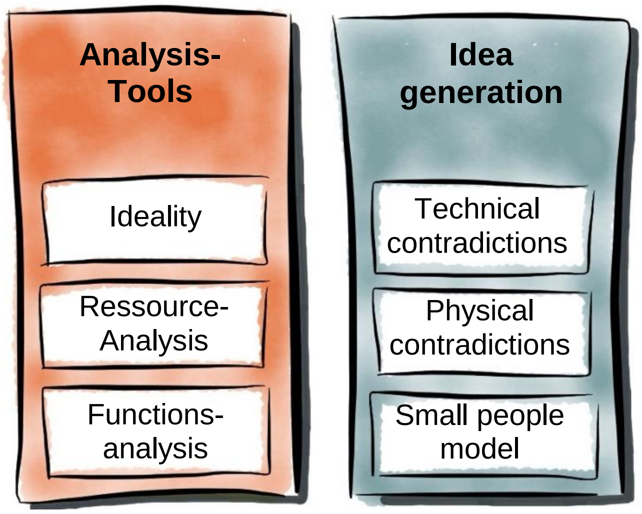


Fig. 1: Overview on used tools for problem solving in considered process

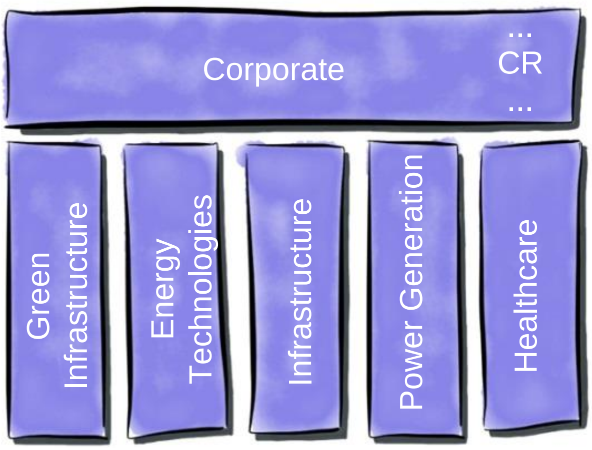
The "technical contradictions" together with the innovative basic ideas are the classic TRIZ-tool. The "physical contradictions" are considered, because it is on first sight contradictious to look for physical features in business processes. The third tool for idea generation is too thrilling to not consider: The "small people" model looks playfully in the result, but requires a lot of creativity and a deep thinking into the problem.

The tools may be associated with one of two groups each (fig. 1). The analysis tools are to decompose, analyse and understand the product, process, or the formulation and hence are the basis for many of the tools in the field of idea-finding. The idea generation tools attempt to generate approaches with the classical tool of TRIZ, the technical contradictions. The challenge is that technical parameters shall be applied within a non-technical field. The second tool, the physical contradictions in combination with the four separation principles is a tool that with the four principles moves away from a sheer technical consideration. The third tool by which solutions should be found are the „smart little people (SLP)“.They first can do without technical termini, however, demand a particular familiarizing with the process.

4. The considered process

4.1. The enterprise ACME

In this section first a brief introduction of ACME (A Company Making Everything) is given and then the research section of ACME is classified within the enterprise. Secondly the business process, which should be improved, is displayed. The example refers to a real company.



ACME has over 100,000 employees and operates worldwide. Employees have their working base spread over the world as well. ACME has a diversified portfolio covering multiple sectors of technology. They cover the field of energy technologies, transportation/ mobility, healthcare, green city applications, aviation, etc. Their turnover is in the Billions US-Dollar.

Fig. 2: Structure of ACME. CR (Corporate Research) is part of corporate

ACME is divided into five divisions: Green Infrastructure, Power Generation, Infrastructure, Power Generation and Healthcare.

4.2. Corporate Research (CR)

Selected was the funding process of Corporate Research (CR). CR employs around 4.000 researchers, is part of ACME Corporate and belongs to none of the above mentioned divisions (fig. 2). CR needs to raise „third-party"-funds (from ACME businesses) for their work. CR firstly performs developments for business divisions of ACME as well as projects independent of specific research assignments.

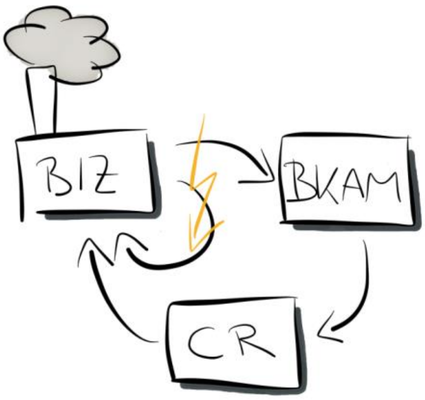


Fig. 3: The business solves the problem on its own or via CR

Researchers work together in teams that are composed project related according to specific needs. The researchers are organized into technical domains (e.g. electrics, mechanics, biotechnologies, manufacturing, etc.). These domains are again split into departments for specific technology areas. To finance research efforts, third-party funds from ACME businesses are required. These come from Corporate and its divisions, but must be acquired by CR.

4.3. The ways of funding

A typical development assignment begins with the business determining that customer requirements have changed. The business has then two alternatives: The development can be continued internally or an external order can be placed. External means that the CR-Center is tasked with solving (fig. 3). The coordinator between business and CR is the Business Key Account Manager (BKAM).

In theory CR is an external contractor for business. CR will define a budget for working out a solution and the processing of the Statement of Work, which will be paid by business. In reality business and Departments know each other respectively their leaders from earlier projects. Over the course of time relationships evolve such that communication happens on multiple levels.

Another part of the funding is provided by Corporate due to strategic demands. The Chief Technology Officer (CTO), at the same time leader of CR, together with the Chief Technologist bring ACME and CR together and award projects to Future Technology (FT), (fig. 4). An example would be research and development in the field of nanotechnology without having a reference to specific applications. The time horizons are 6 to 10 years for "long-term long-term" projects or three to six years for "short-term long-term" projects. Differences on the one hand are concealed in the time horizon, on the other in the financing of the project. While FT projects are exclusively

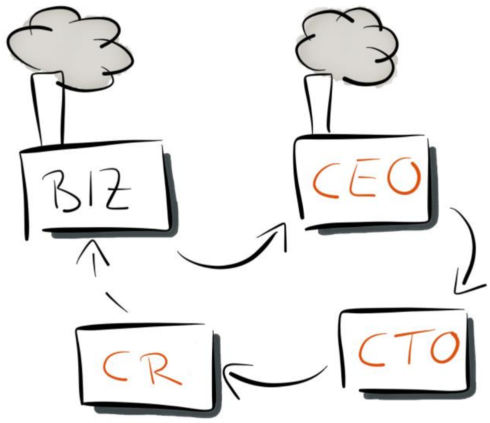
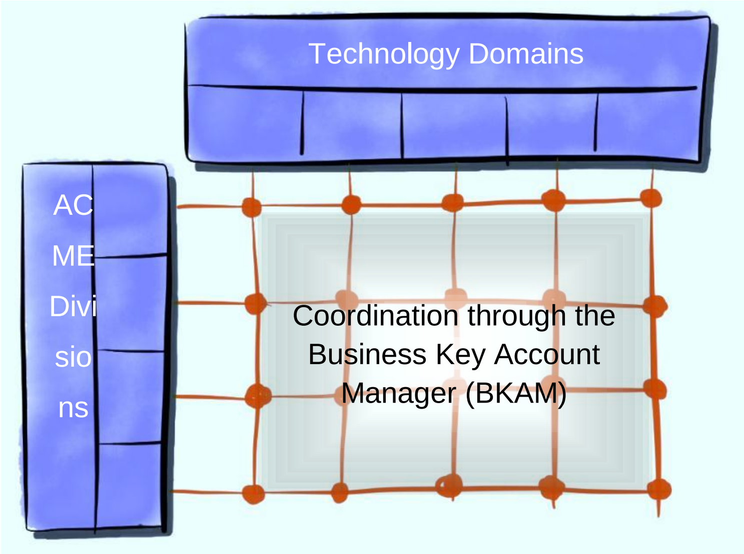


Fig. 4: Future technology development

financed by ACME, short-term long-term projects are subject to a mixed financing between corporate and at least one business. The ACME business divisions are organized according to products, whereas the CR is organized according to domains (mechanical engineering, electrical technology, chemistry, biotechnology, manufacturing, etc.). A technology like electrical technology has a number of laboratories, e.g. for drive engineering, measuring and controls technology, or energy transfer. Drive engineering itself is divided into motors, gearboxes, health monitoring, etc. Below this lies the last structure level, where in the generator-laboratories specialists for 50 Hz-technology, 60 Hz-technology, large-scale generators above 10 MW, low-scale generators below 10 MW, etc. can be found. The coordination of the domains to the ACME divisions and businesses is carried out by the BKAM (fig. 5).



4.4. The problem

The money, which is spent for research purposes, is provided by businesses. Generally financing is done problem- or project-based. This means that third-party funding has a permanent meaning for CR. Several times per year new projects are established or existing projects need fresh money because more time or more co-workers are needed.

The procedure described in the last section takes a lot of time and employs many people binding resources not available for research. Not only must budgets be negotiated, also research projects themselves are called into question. Changes in budget have influence on the time, which is available for development and influence the number of personnel of the laboratories. The question to answer is thus defined as: Can the funding process be handled more efficiently?

5. Application of the analysis tools

5.1. Ideality

The process doesn't need to take place if the researchers would not need money for research and no researchers would be needed for researching. If it needs to happen it entails no costs, needs no time, and takes care of the proper allocation of the most important resources money and work power. As a result it illustrates the visions of the management and ensures that the proper technologies can be developed.

5.1.1. Researching without research

Research without employing researchers seems difficult to believe. What if ACME were capable to have access to "all knowledge" and has a database, which not only makes knowledge available but also can abstract to draw analogies. The enormous potential behind this is easily conceivable. The classical tool "contradiction matrix" is an approach of this kind, but, however, neither relieves the user from the abstraction of the specific problem nor from the specification of an abstract approach.

Researchers working without producing cost also seem impractical. Nevertheless crowdsourcing exists, where originally internal company task are taken over by volunteers, normally internet-based. Around crowdsourcing services have established, where enterprises shortly present their problem, registered users then can request a detailed task definition. Enterprises determine a filling date and then only pay for the solution of the problem.

Starting point of the tool “ideality” is the elimination of the considered product or process. The object of this study, however, is the improvement of the process – not its elimination.

5.1.2. Restraints from the ideal process

If the process should take place, it must be checked how many respectively how few restraints must be made. Negotiations about budget heights are not needed if it is known in advance to all participants how much the development project would cost. Here an exact documentation of all development projects, which were completed so far, could help to estimate future demands. The negotiation is giving way to an objective assessment of requirements. Any bargaining or haggling must be avoided because the project manager deliberately demands more than he wants to get, to get what he according to his opinion needs.

Furthermore, negotiations would no longer be necessary if it would be possible to create a kind of research value. Developments would be estimated according to the degree of complexity, for example divided and priced into three categories. Lengthy negotiations could be avoided if several teams could perform a development and would take part in a tendering procedure or reverse auction for the order. The negotiations would be reduced to the submission deadline, where the quickest or most favourable team gets the order, possibly under the conditions of the second price sealed bid.

5.2. Resource-analysis

The resource analysis demands the full utilization of all present resources (Hentschel, Gundlach, & Nähler, 2010). In the following, compromises on the completeness are made for some resources, because the long-term objective is not the increase in efficiency of some process details but the “big picture”.

5.2.1. Materials

Money is a material resource. Less decisive is the flow between (settlement) accounts but the where from, for what and where to. Money is a means to an end and in a wider sense serves for information and knowledge procurement. Money does not appear in the classical checklist, which was created for products. Analogously, money gets back its initial function: It is means of exchange. In return, similar to a service contract not knowledge but the search for knowledge is promised.

5.2.2. Fields

If one takes a broader view on the term “fields” the environment in the sense of the “Five Forces” of Porter is apparent. According to Porter, forces acting from outside determine the success of an enterprise. The competition in the existing market, potential new competitors, powerful suppliers and customers as well as the danger of substitutes defines the corporate success (Porter, 1979). Independent from the corporate success these five groups are potentially available as partners as well for the funding in the form of cooperation partners as also in the field of research as partners.

5.2.3. Room

For a business process the resource plays a roll insofar as people working side by side can consult each other or make arrangements more quickly. So communication can tend to happen more quickly and informal than by phone or e-mail.

5.2.4. Time

The resource “time” plays a roll several times. On the one hand it is a disturbing factor within the funding process, because the complete tuning needs time. On the other it is a factor, which in the frame of the actual research can be divided by deployment of personnel. Has an enterprise missed a development, market entry barriers threaten in form of patents. From this sight, time is a resource, which is currently not available and therefore has a prominent meaning.

5.2.5. Information

To present the flow of all information within a complex business process is rather impossible. Not only the formal information flows must be presented, but also all “loopholes” like “corridor talks”. Particularly processes of decision finding are complex, need days or weeks, are put aside and retrieved again. In the following, the necessary resources for the actual process of the category “information” will be explained.

Even if the terms “information” and “knowledge” are not synonyms, knowledge belongs to that issue of the resource checklist. In this sense knowledge means “to have information about”. This (technological) knowledge is the third resource which to gain is the overriding aim of the considered funding process. Not the funding is decisive but the acquisition of know-how.

The category of information also includes strategic decisions made by the board of directors, which are trendsetting for the FT-projects of the company. Likewise information is present to Product Lines, which encourage them to commission specific developments. The information comes from communication with clients and suppliers as well as from market observations and competition analyses. To the latter belong the patent analyses to remain currently updated about the state of development in other companies.

5.2.6. People

Personal resources are, as far as it concerns ACME, either organization units or positions within the enterprise. The businesses earn the money, which is available for research purposes and decide on product specific research, e.g. the efficiency increase of a gas turbine. Furthermore, businesses are potential beneficiaries of developments, which are commissioned by other product lines.

Another resource are the laboratories of CR. Within them the researchers group to project related teams to perform development orders. Furthermore, they are knowledge-holders in their special field. They are potential knowledge sources for other laboratories in so far as knowledge is transferable to other fields.

5.3. Useful, harmful and necessary functions

Aim of the following consideration is to improve the process and not to abolish it. It applies to all processes that they need time. Since time is to be saved, it is applicable for all listed functions that they are harmful regarding the factor time.

Businesses produce money. The money for research finally comes from business. The consideration whether its function is necessary or useful is difficult. The function is necessary because without it no money for research is available. With the same argument, the collection is necessary. It is a value-adding function.

Businesses transfer money to ACME Corporate. This procedure in the sense of outflow is unproductive. Even if the outflow potentially lets know-how flow back, it does not constitute a useful function on its own. For the funding process, it is necessary like the generating of money and useful at the same time. Accumulated the produced money is the basis for discussion for the decision about the targeted projects. The collecting of money is no value-adding function.

CTO and Chief Technologist define the focus points: The definition of strategic research focus points is useful (e.g. ACME believes that the future of energy supply lies in Combined Heat and Power). It is useful, harmful and necessary at the same time. It is necessary, because resources are not unlimitedly available and an allocation of the scarce resources must take place. The definition is useful to give a direction to the company as a whole in the sense of a vision. At the same time the definition is harmful due to two reasons: The strategic decision might be wrong. Furthermore non-key topics are systematically underfinanced.

The budget definition as such is necessary as long as money must be paid for research and it is harmful because it caps the research activities of CR. Useful is a budget definition because it makes – independent of the amount of the budget – in the first place research possible and secures the continued existence of a technology company like ACME. Good is that from the moment of determination it will give planning security. Since the preceding planning security itself was triggered by the budget planning, no importance can be attached to this supposedly positive effect.

As initially mentioned, the funding process at the end is only a „means to“. It precedes the research work, but does not help it. Accordingly, many of the listed functions are only necessary but rarely value-adding.

6. Application of the idea generating tools

6.1. Technical contradictions and innovative basic principles

Difficulties in applying the technical contradiction arise in that an economical problem must be expressed in technical termini. Weight, length, area, and volume are characteristics which a process does not own. “Length“ e.g. could be defined as duration. The targeted saving of time is better described by the parameter 25, losses of time.

The determination of the contradiction is made in three steps:

1. Identification of parameters to be improved,
2. Identification of deteriorating parameters and
3. Working out of the relationship between 1. and 2.

Firstly, the worked out parameters are defined in a way that they can be expressed in technical parameters.

6.1.1. Parameters to be improved

Main issue of the whole process is that the people involved in the process should invest less time. This circumstance is described by two similar parameters: „Speed (9)“ and „loss of time (25)“. A further parameter establishes a relationship between output and input.

At first sight it disturbs that „costs” cannot be listed as a parameter: Lastly most improvement and restructuring means focus on cost reduction. The parameter „use of energy by stationary object (20)“ as well as the already mentioned time losses could be a replacement.

The tool “ideality” lead to the idea to build up a knowledge database. This could increase the „ease of operation (33)“ and the „extent of automation (38)“.

The process is confusing. Desirable would be a „decrease of complexity” or complexity of the structure (36).

Altogether six technical parameters could be identified, which play a role as part of the process improvement. In the next step the parameters must be identified, which commonly decrease if one tries to improve one of the seven parameters.

6.1.2. Parameters not to be worsened

Restructuring measures are associated with costs. A synonym is the „use of energy by stationary object (20)“

Information is lost due to time pressure or in a process involving several people is not made available to all participants. The technical parameter is named „loss of information (24)“.

Projects with strategic orientation are subject to uncertainty because technical developments and trends must be anticipated. If time should be saved here the „reliability (27)“ of these predictions may be affected. If the predictions are considered as a product, the „manufacturing precision (29)“ should not be affected.

Hence four parameters are identified, which commonly decrease if one of the above-named parameters shall be improved. The list is not final, shows, however the possible adaptation of the technical parameters.

6.1.3. The contradictions

In the further process not all possible correlations shall be investigated. It seems useful to investigate only the fields with strong correlations, which fit into a 3x3 matrix. In the next step the innovative principles are listed from the contradiction matrix of Altshuller (Tab. 1).

(Bannert & Warschat, 2007) state that the parameter “Replace mechanics” from an economical standpoint is being a simplification principle. A “phase” should be replaced by another simpler one. Regretfully, a simplification is exactly the purpose of the consideration. This means that further synonyms for “simplify” must be developed, like “stereotyping”, “coarsing”, and “flatting”. Groups or categories of research projects could be formed, whose budget, number of personnel, and time frame are defined. The development orders brought forward by businesses are for example divided into three groups. On the one hand this allows a quick cost overview, on the other hand the projects would be like building blocks, which are assembled to a house and define the annual budget of CR. Additionally, Product Lines could obtain the competency to independently award orders to the first group. Precondition for a categorization is a thorough analysis of as many projects as possible to clarify the fundamental feasibility as well as the criteria for a splitting into groups. For the term “**copy**” synonyms exist like duplicate, imitate or repeat. The target would be to standardize negotiations that they become quicker to perform. Therefore, a careful analysis of preceding projects would be necessary. Even in research duplication is possible: A knowledge database would make performed developments company-wide available, even a matrix made up from company-internal solutions analogue to the contradiction matrix would be possible.

Table 1: Classical contradiction matrix 3x3

Table 1: Classical contradiction matrix 3x3	Losses of information	Reliability	Precision of production
Speed	13 26	11 35 27 28	10 28 35 23
Loss of time	24 26 28 32	10 30 4	24 26 28 18
Automation	35 33	11 27 32	28 26 18 23

The principle "**preliminary action**" could take ahead elements from the process or preterm things. Preliminary work would mean that more work is transferred to ACME business. They could be awarded with competence to contact CR by themselves or to get access to a databank, to get access as early as possible to available solutions.

Working out specific ideas by means of the contradiction matrix is not easier but also not more difficult than as if physical products are concerned. Interesting ideas could be generated even if the factor to be improved "costs" had to be made more comprehensible. The method of not formulating concrete contradictions first, but selecting the innovative base principles based on their frequency has worked out well.

6.2.1. Physical contradictions and separation principle

A business process has neither physical, chemical nor physiological properties. Nevertheless contradicting properties may be demanded. In the following the contradictions are formulated in a way that the desired property proceeds the undesired property.

6.2.2. Size

Many people and departments of ACME are involved into the existing process. Their coordination requires expenditure and it could be desirable if fewer instances were involved.

On the other side the funding decisions, which must be made are linked to different locations within the company.

From these two differences the contradiction "small versus not small" can be derived: The process should be small or compact, on the other side it may not be small. The size of a process describes the number of necessary process steps or the involved instances. A survey on opinion-forming should be small to be able to conduct it quickly and inexpensively. It should not be small because as many as possible persons should be inquired to obtain a representative result. This contradiction applies to the considered process: many instances are involved and it would be desirable to keep the process compact. On the other side different parts of the process concern different parts of the company, that all should be involved.

6.2.3. Complexity

Independent from the extent of the process is its complexity. Even if a correlation between size and complexity may be assumed, it is not a mandatory requirement and hence is another perspective on the process.

Within the process, different decisions are made by different people. Short- and long-term decisions must be correlated, instances are involved to be responsible for decisions and money transferred through the company – a simplification would be desirable.

At the same time, a variety of persons involved into the process is desirable. It takes account of the fact that projects have different scopes and research is discipline specific. The range of decisions to be made makes the complexity to seem imperative. The contradiction is that the process should be "simple versus not simple"

This property aims at the complexity of a process. A loan appraisal should contain many aspects and lead to an informed decision by the bank. On the other hand low complexity is demanded to be able to standardize processing and save costs. The considered funding process is complex although some simplifications have been taken. It should be less complex to reduce the effort.

6.2.4. Speed

A further aspect is the duration of a process. It correlates with the size and also with the complexity of the process. So far the purely temporal aspect was lacking because it is incomprehensible that complex processes involving more people run faster.

The factor time plays a role in several respects. On the one hand many meetings and agreements are necessary, which -already considered in isolation- cost time. Furthermore, in a company like ACME the decision makers are spread over the whole world and hence work in different time zones. Both factors are harmful to the process.

Time in the sense of "taking time" is requested, when it comes to overviewing processes completely. Furthermore, it can be wanted not to make poor decisions. The third contradiction is "fast versus not fast" and refers to the duration of the process. A process should speed up because it costs less money, or more processes can take place in the same period. At the same time it should not happen too quickly because certain steps will have errors when they are performed quickly.

As an interim summary it can be stated that also in business processes, physical contradictions exist. The next sector addresses the application of the four separation principles.

6.2.5. Separation

To make the principle of separation more tangible, the first three principles can be formulated as questions:

1. Where the condition "A" and where "not A" shall be applicable?
2. When the condition "A" and when "not A" shall be applicable?
3. Under which preconditions "A" and "not A" shall be applicable?

Separation in area for solving the contradiction simple-not simple: In the sense of an interleaving, employees of CR can go to their customers (business) to work there. It would be desirable if an employee with special skills not only works for one but for different businesses.

Separation in time for solving the contradiction quick-not quick: With a bidding process the businesses would have the opportunity to enter their problems or readily defined projects with a budget into a database. The researchers could later decide themselves for which project they want to bid. This solution reduces the time all participants have to invest without having to make unwise decisions.

Separation within the structure for solving the contradiction small-not small: Small teams for small projects. If businesses could manage their budget by themselves up to a certain limit, the instance of the business CEO would be eliminated. Only after exceeding this limit more instances are to be involved.

Like the innovative basic principles also the separation provides interesting approaches. Although technical contradictions are basis of the TRIZ-tool the application on the funding process succeeds.

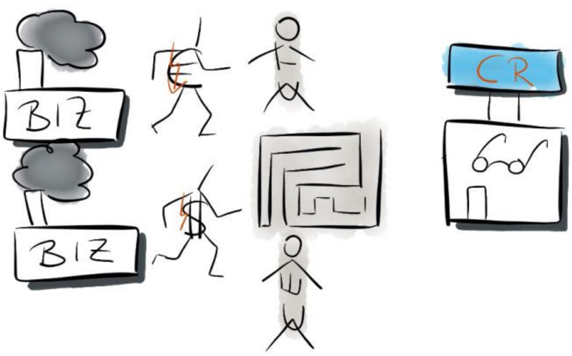


Fig. 6: Funding and problem pathway to CR

6.2.6. Small People Model

The challenge of this tool is to assign duties to small people. The proper abstraction is important to describe the problem as pointed as possible (but not necessarily comprehensive).

Next, small people must be found, who can solve the problem. Finally the way is searched from the small people to concrete approaches. Opposite to other TRIZ tools, which after abstraction need further tools, the little people just require the understanding of the considered process. This means that a lot of creativity is demanded.

Within the funding process are little money people, who want to bring capital from business to the little research people in the laboratories. Furthermore, little problem people exist, who also walk from business to the laboratory. In between stand little illicit people, who try to stop the little money people as well the little problem people or send them on a detour. As soon as the little money people as well as the little problem people have arrived at the little research people, both the little research people and the little money people start to build little knowledge people out of the little problem people. As soon as the little knowledge people are finished, they walk from the laboratory to business. This process does not describe the funding process completely, however, already identifies problems (Fig. 6).

Within a next step, the roles of the present little people must be questioned, little people ceased or added. Can little illicit people let the little money and problem people alone, but distract the little knowledge people that they go through the company? The instances, which must be passed during the funding process, should make use of their primary role, to widely distribute the returning knowledge.

Could the construction of the little knowledge people pass earlier? This would mean that the research should happen in business. Can little research people work without little money people? Crowdsourcing is a method to profit from the knowledge of many people without having to pay for all involved persons. A further alternative would be research on demand in the hope to be able to sell the knowledge later.

Can little money people work without little research people? Only if no research is done. It would not be necessary to research, if the knowledge already exists within the company but is not known. A company-wide knowledge database would be a solution. Alternatively subcontracting could be considered. In this case, little money people would be exchanged against little knowledge people.

Two more questions remain unanswered:

- Could little illicit people be made to help the little money and little problem people on their way instead of stopping them?
- Could little knowledge people be built from something else?

Also the third TRIZ tool was able to contribute approaches to the problem. Meanwhile the approaches repeat. In the best case it means, that these approaches are particularly valuable. It could, however, also be, that the sequence of the application plays a role: Probably the little people would have needed different approaches if they had been used as first tool.

7. Derived approaches

Many different ideas were developed, which all could improve the existing funding process. These ideas can be divided into three categories. The first type questions the complete funding process as well as the consecutive research activities. The second type leaves the process as it is, however modifies it in parts. The third group does not deal with the process itself, but provides help. Due to the substantial changes, which were proposed within the first group, solutions from this group are rarely combinable with solutions from the two other groups. The compatibility is increased, if the approaches are applied in a diluted form or as supplement. The solutions from the second and third group are randomly combinable.

A division into the above mentioned three groups is not only an interesting interim result of this work. It furthermore serves as a preliminary assessment of the possible obstacles during an implementation within the company: Genuine changes will find fewer acceptances. Changes on parts of the process mean less costs, demand, however, familiarization and under circumstances additional work. Additional helps cause additional costs.

Utilization of networks for research. Crowdsourcing. Independent whether unknown people (Crowdsourcing) or persons associated with the company and enterprises like suppliers or clients (cooperations) join the development, this type of knowledge generation should be taken into consideration. Opposite to cooperations, crowdsourcing has the potential to replace the whole research activities of ACME.

Build of a (company-wide) knowledge database. It allows access to the whole know-how of the enterprise. Important is that build and access happens group-wide, to maximize the range and show semantic properties.

Award of contracts by standardized bidding procedures. If a problem could be solved by different departments – probably even by different approaches – the project might be put up for tender. Provided that the problem definition is clearly defined, no negotiations would take place, since laboratories would bid on research orders.

Formation of business-wide workgroups and exchange of employees. On the one hand exchange between businesses with similar problem definitions should be promoted. In regular meetings, problems could be discussed and under certain circumstances commonalities may be found. A similar approach adopts the exchanges of employees between purchaser (business) and contractor (CR). By becoming acquainted with the respective different vision on problems the mutual understanding can be encouraged. It is conceivable that the lengthy formulation of the research object can be developed more efficiently.

Research on Demand. CR itself could promote projects, which are considered to be requested by the company earlier or later.

8. Lessons learned about TRIZ for biz Org Structure Application

The tools for analysis of the processes were easy to use. The resource analysis is like with the analysis of complex products elaborate. There is a certain danger of losing oneself in an excessive analysis. On the one hand all resources should be collected, on the other limits must be drawn. Not only the involved people but also their relations are diverse. Within a process with only 4 resources exist already 10 relations if there is only one relation each between all of them.

The function analysis was like the resource analysis very elaborate and could also have been even more expanded. The introduction of an additional criterion, the added value, turned out to be useful. This one does not appear in the classical function analysis. Ideally, the function analysis should be performed by at least two persons together. It may happen that an issue is recognized and tracked, which in this form does not exist at all, but is interpreted into the process. This not only applies for an extended application on business processes but also for the original use within the classical TRIZ.

The functionality for the funding process has worked just as well as for a product. During utilization one aspect has to be noted: This consideration first begins with the elimination of the process because it is not necessary. If this thought is performed with people, whose job might be lost hereby, the consequent application of this useful tool will be difficult. The elimination of the process is only the beginning. The more iterations are performed the further the result moves away from the complete elimination.

The technical contradictions as a first tool for idea generation have delivered many results. In the classical contradiction matrix as well as in the matrix 2010 parameters can be found, which are applicable to business processes. Also for the innovative basic principles, many non-technical analogies exist. Comparatively as amazingly unwieldy the business

Contradiction Matrix from (Mann, D., 2007) has presented itself. Due to the fact that the matrix was specially adapted to economical tasks, many universal parameters became lost. Of particular help were the hints, which are available in the same book for interpretation of the innovative basic principles.

The physical contradictions can also be formulated for business processes. Based on additional examples it should be examined, whether more than the three contradictions in business processes exist. The separation principles are due to their abstractness arbitrary applicable.

As last it was tried to generate new ideas together with the small people. The problems of formulating the tasks to be satisfied by the small people are similar in products and processes. For more complex business processes, the decomposition into several sub-problems is recommended to prevent the number of "persons" to become too large.

TRIZ tools are applicable to business processes. They are suitable for analysis as well as for idea generation. Complex processes can for reasons of clarity be divided into sub-processes. How simple a process may be that it can still be processed with TRIZ tools, would be object of further considerations. If further studies were to be carried out, they should focus on two issues: One is applying more TRIZ tools to the improvement of business processes. The second would be trying to find the limits – if they exist – of the application to business problems.

References

1. Koltze K., Souchkov V. „Systematische Innovation", (F.J. Brunner, Hrsg.), München: Hanser Verlag, 2011.

2. Kim K. „The Creativity Crisis: The Decrease in Creative Thinking Scores on the Torrance Tests of Creative Thinking", Creativity Research Journal, 23(4), P. 285-295, 11/2011.

3. Hines, T. „Left Brain/Right Brain Mythology and Implications for Management and Training", The Academy of Management Review , 12 (4), 1987, P. 600-606.

4. Hentschel, C., Gundlach, C., Nähler, H. T. „TRIZ - Innovation mit System", München: Hanser Verlag, 2010.

5. Bannert M., Warschat J. „Vereinfachung von Managementmethoden durch TRIZ", in P. Rietsch & P. Rietsch (Hrsg.) TRIZ – Anwendung und Weiterentwicklung in nicht-technischen Bereichen (Pages 61 – 90), Wien: Facultas Verlag, P. 11, 2007.

6. Mann D. „Hands-On Systematic Innovation for Business and Management", Bideford: Lazarus Press, P. 16, 2007.

7. Porter M. E. „How Competitive Forces Shape Strategy", Harvard Business Review, P. 203-212, March-April, 1979.

Author (co-author) to contact: Oliver Mayer, mayer@ibom.de

TRIZfest 2014

Analogy Based Idea Generation with TRIZ

Cheol Woong Kim[a], Min Sik Ryu[b], Jun Hee Cho[c], Chae Moon Lim[c], Bo Min Park[c], Yong Kyu Lee[c], Hee Jin Lee[c], Jae Hee Song[c] and Kwon Hong[c]

[a] *R&D Division in SK hynix Inc., Korea*

[b] *Seoul National University, Korea*

[c] *R&D Division in SK hynix Inc., Korea*

Abstract

There are numerous studies and methods on creativity and people strive to enhance creativity through artificial methods. However, controlled thinking may degrade the performance of idea generation. In this context, this study suggested mixed approaches, and supported it through experiment.

Keywords: analogy, creativity, idea generation, TRIZ

1. Introduction

This study focuses on how to improve creativity, namely idea generation skills. The first purpose of this paper is to propose better method of idea generation. Secondly, this study is to confirm the effectiveness of hybrid analogical idea generation method with experiment and case study.

2. Research on creativity

2.1. Definition and attributes of creativity

As a definition of creativity, Michael Mumford suggested: "Over the course of the last decade, however, we seem to have reached a general agreement that creativity involves the production of novel, useful products" (Mumford, 2003). A first unique characteristic of creativity would be novelty. Practical or theoretical creativity requires that something original is produced, or at least added, something that has not been made before. Most researchers prefer to differentiate between normal thought and 'creative' thought, designating the latter as "productive"(Wertheimer, 1945), "lateral"(de Bono, 1970) or "divergent" thought (Guilford, 1986). A second defining characteristic of creativity is that its result should be adaptive or useful (Simonton, 1999). Creativity can be represented by fluency, flexibility, originality (Guilford, 1950), uncontrollability, chance, and randomness. Some of attributes of creativity - uncontrollability, chance and randomness – are out of control. Creativity can't be realized only by intentional control on thinking, and intentionality may cause constraints on thinking.

Creativity can be fully achieved through the unintentional thinking – free or random thinking also (Ryu, 2013).

2.2. Approaches for enhancing creativity

Methods for improving creativity mentioned in the previous chapter can be classified into two approaches. One is a structured approach and the other is a random approach (Ryu, 2013). Firstly, the structured approach pursues an intentional or forced creativity. Most thinking methods - CPS, Brainstorming, Six thinking hats, TRIZ (Altshuller, 1979), Synectics (Gordon, 1961) and so on - can be classified as the structured one. This one-sided approach is not consistent with the importance of uncontrollability as a critical attribute of creativity, and may suppress free or random thinking (Ryu, 2013). Secondly, the random approach - Lateral Thinking, Random Word (de Bono, 1995) - pursues an uncontrolled creativity (Ryu, 2013).

2.2.1 Synectics - Example of structured approach

Synectics was developed by George M. Prince and William J.J. Gordon, originating in the Arthur D. Little Invention Design Unit in the 1950s (Wikipedia). Synectics has been called as an artificial vacation by some researchers because it seems to let us take a holiday from the problem by not having to think about it consciously for a while, and it encourages us to put aside our business-suit-thinking, our usual analytical frame of mind; but it is an artificial vacation because while our conscious enjoys making the analogies our preconscious is hard at work on the problem (Prince, 1969). The role of Synectics is to help individuals oscillate between rational and irrational thinking and detaches us from the problem and then brings us back to it. In comparison to other creative problem solving methods, Synectics doesn’t have many tools. It utilizes analogical techniques. The principles of making the familiar strange and the strange familiar are the underlying ‘tools’ that generate novelty through the use of direct, personal and compressed-conflict analogies (Gonzalez, 2001).

2.2.2 Lateral thinking and Random Word - Example of random approach

The term Lateral Thinking was invented by Edward de Bono in 1967 and is defined by the Oxford English Dictionary as “a way of thinking which seeks the solution to intractable problems through unorthodox methods, or elements which would normally be ignored by logical thinking”. Lateral Thinking is quite different from vertical thinking or logical thinking. Where logical thinking is concerned with “truth” and “what is”, Lateral Thinking is connected with “possibilities” and “what might be.” Moreover, in logical thinking an individual moves forward by taking sequential steps. Lateral Thinking strives to establish new directions and perceptions. The main principles of Lateral Thinking are ‘provocation’ and ‘movement’. Provocation allows our mind to get out of the established track and with movement we move forward from the new track (Gonzalez, 2001). Random Word (or Random Input) is a creative thinking tool associated with Edward de Bono and his lateral thinking programs. Dr. de Bono chose random word as a first lateral thinking tool for a number of reasons. It seems totally illogical and unlikely to work. Actually, it's totally logical. Also, it may be the easiest of the tools to use for provocation. Besides, it's very powerful. Then, how to use Random Word? The first thing we need is the Random Word itself which is classed as the initial stimulus. Then we establish a Bridging Idea which is an idea which is based on the stimulus. We then use this idea as a bridge between the stimulus and an idea which we could actually use on our problem. What do we have to be careful of when using Random Word technique? We should not just look for some sort of connection between the Random Word and the focus. This does not have any stimulating effect at all. This task is not to connect the two, but to use the Random Word for stimulation. Secondly, we need to force ourselves to use the original random word. Otherwise we will simply be waiting for an easy connection and we will not stimulate new ideas at all. Also, we should not take a series of steps in order to arrive at a new random word. (de Bono, 2008).

3. Research on creative cognitive operations

In this chapter three different cognitive operations will be discussed. They are generally mentioned in the literature on creative cognition area, yet rarely distinguished from each other properly.

3.1. Application

A creative cognitive operation might be identified as application: the adaptive use of existing knowledge (Welling, 2007). Creativity is required for fitting reality into an existing conceptual format. This operation consists of the creative adaptation of existing conceptual structures to fit normally occurring variations. The most obvious example of application is everyday activity. In the realm of intellectual activity a good example of application may be the work of a lawyer. The lawyer has to find the most advantageous fit between the facts present in the case and existing juridical concepts. Surely, this is a creative and complex task. Yet this creativity is limited in the sense that the lawyer cannot invent new concepts or laws but has to work within the existing framework; no new conceptual structures are being created. Also, a considerable part of experimental and scientific work can be considered as application (Welling, 2007).

3.2. Analogy

A second creative cognitive operation commonly identified is the use of analogy. Analogy is a cognitive process of transferring information or meaning from a particular subject (the source) to another particular subject (the target), or a linguistic expression corresponding to such a process (Wikipedia). Many researchers have referred to analogy as a key concept in creativity. Michael Wertheimer (1991) virtually defined insight as analogy: "discovery of the applicability of an existing schema to a new situation". Weisberg (1995a) explained several artistic and scientific achievements by analogical transfer as follows: “situations in which information from a previous situation is transferred to the new situation that is analogous to the old.” Dunbar (1995) identified three different kinds of analogical reasoning. Local analogy occurs when the scientist draws an analogy on a single characteristic from one experiment to another; in regional analogy a whole system of relationships from a similar domain is mapped onto another domain; and long-distance analogy is used when these systems come from an entirely different domain. No new cognitive structure is required. In both application and analogy operation, existing structures are used creatively. In the case of an application operation, they are used to deal with variations within the habitual domain; in the case of analogy, the existing knowledge is transferred to a new context. Most insight problems require solutions that are based on the use of analogy. An illustration of a scientific field in which the use of analogies is particularly frequent is chemistry. Numerous concepts such as bonds, shells, loadings and energy are mere analogical approximations to model molecular interactions (Welling, 2007). Analogy plays an important role in TRIZ, also. From the viewpoint of TRIZ, most innovations are not brand-new but new application of existing solutions in different domain. The specialty of TRIZ is the systematic approach to find analogous solutions. When we solve problems, we first define domain problem and convert it to TRIZ standard problem, such as contradiction. Then we determine the TRIZ special solution by using TRIZ tools such as Inventive & Separation Principles, TRIZ Trends or Laws of Evolution, and so on. TRIZ delivers a systematic way to find analogous technical solutions.

3.3. Combination

Combination is the merging of two or more concepts into one new idea. It differs from analogy in the sense that this operation requires the creation of a new conceptual structure (Welling, 2007). Concepts can be combined either spatially - combined simultaneously – or temporally in which the combination results from the sequential applications of existing ideas (Simonton, 1999). Mumford et al. (1991) added that combination can not only be obtained by the combination of previously distinct concepts, but also by the rearrangement of elements within an existing concept. Combination of ideas is probably the most frequently invoked mechanism for explaining creative ability. Martindale (1989) stated that creative thought comes from new combinations of old ideas. Davidson and Sternberg (1986) proposed a selective combination process that is based on putting together the element of a problem in a way that previously has not been obvious to the individual. Finally the combination operation is essential for concepts such as "morphological synthesis" (Allen, 1962), "bissociation" (Koestler, 1964), and "conceptual combinations" (Hampton, 1987). An example of a scientific field in which combination thinking is predominant is engineering (Owens, 1969), both in its temporal and spatial variants. Many technical solutions are the result of bringing together existing elements in a useful and practical manner.

3.4 Principles of Idea Generation

What is the core principle of idea generation? Analogy and combination are both mentioned frequently as the principles of generating ideas (Ward & Kolomyts, 2010; Welling, 2007; Hampton, 1987; Genter & Markman, 1997). Namely, the principles behind idea generation tools - Synectics, 40 principles of TRIZ, Lateral Thinking, Random Word and so forth - are analogy and combination. But the classification between them is merely theoretical, not practical. So, the present study denominates them as just analogy (analogical reasoning). How can we analogize more effectively? The core of analogy is the connection between the two concepts, where one of them is already determined. So, the source could be important. Which source can be useful? Ward et al. (2004) noted that creative ideas could be derived from abstract concepts. On the contrary, ordinary ideas can be created by the concrete concepts. The specific source may lead to many, low quality ideas, and abstract source may lead to fewer ideas, but the ideas created will be more valuable (Ryu, 2013). In this respect, unrelated words and random word can be useful.

4. Hypotheses and Experiment design

This chapter will propose hypotheses to enhance idea generation. The hypothetical proposals can be summarized as follows (Ryu, 2013):

A. Think hard. Human do not maximize their limited ability (Stanovich, 2009).

B. Think free willingly. Intentional control may provoke trade-offs in various aspects (Heath et al., 1998).

C. Think randomly. The problem of efforts to improve creativity is the bias as the structured approach.

D. Think through analogy. The principles of generating idea are analogy (and combination). If analogy is used properly, more and better ideas can be generated.

E. Think using hybrid methods from A ~ D. The hypothetical proposals above may also provoke another constraint like a bias. The techniques have to be used in a mixed way.

4.1. Experiment designs

This is the reappearance experiment of Ryu's experiment. This research proposes the hybrid method with effort – i.e. free-association thinking with no aids, analogy with structured and random cue. This mixed method is named as hybrid analogy in this study. Hybrid means a double mixed method in two aspects - process and idea generation source (Ryu, 2013). Participants were 103 employees who were involved in the TRIZ training course of the company. Cases that the number of generated idea is under three, or cases in which participant does not understand the task properly were excluded. The given task was to find new functions of a 1.5 liter empty plastic bottle. Imagining many functions as possible were recommended, and 15 minutes were given for the task. Participants were randomly assigned into three groups. First control group (M1) was allocated as free-association group with no aids. Second control group (M2) is applied by conventional analogical reasoning. They were provided initially with a hint sheet. Third group (M3) was instructed with hybrid analogy as an experimental group. They were provided with a hint sheet 7 minutes and 30 seconds after the start. The hint sheet consists of structured and random word.

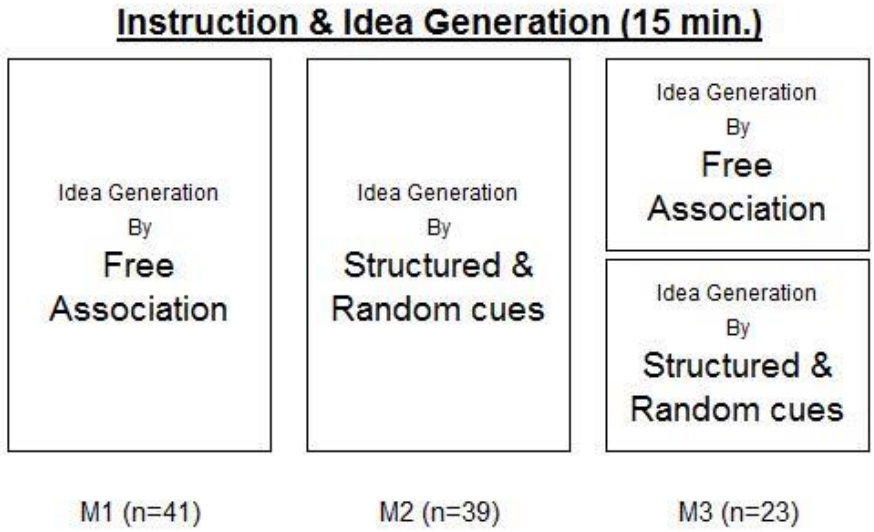
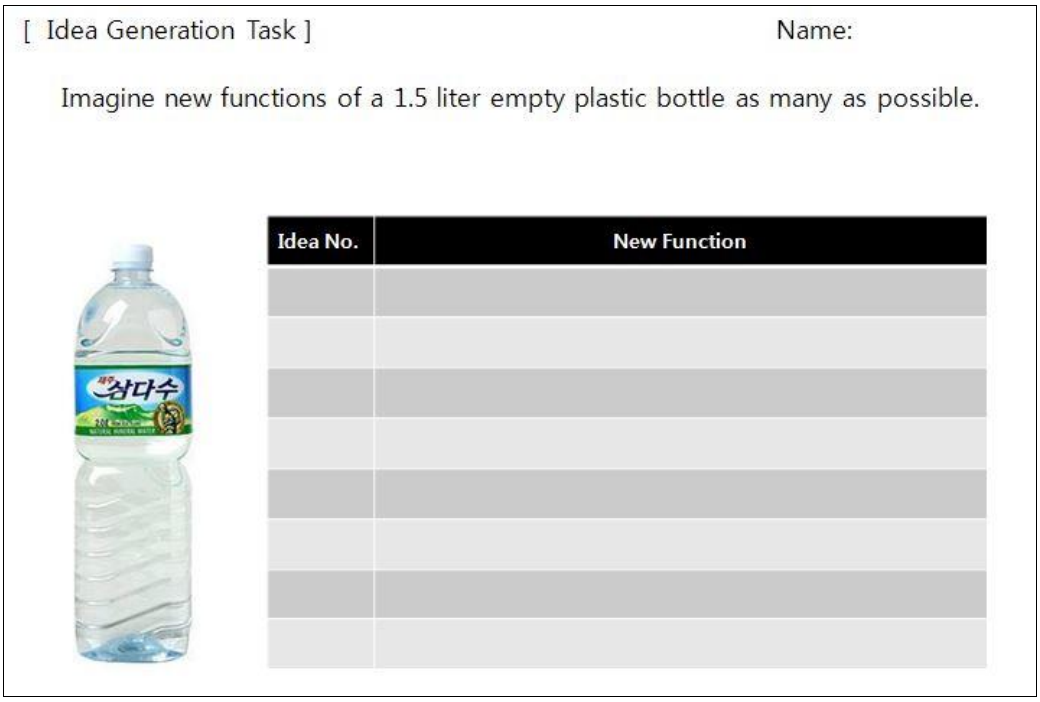


Figure 1. A graphical illustration of the experiment procedure

The hint sheet consists of structured and random words. Structured cues are conceptual words of TRIZ 40 principles. Random cues are conceptual words adopted from de Bono's random words table (de Bono, 2008). All the task sheets used are as follows



[Idea Generation Task] Name:

Imagine new functions of a 1.5 liter empty plastic bottle as many as possible.

Idea No.	New Function

Sheet 1. Task sheet for experiment with no hints

[Idea Generation Task with hints] Name:

Imagine new functions of a 1.5 liter empty plastic bottle as many as possible using hint words below.

Hints : Segmentation, Extraction, Merging, Nesting, Curvature Increase, Dimension Change, Feedback, Porous Material, Color Change, Parameter Change, Phase Change, Thermal Expansion, Book, Prison, Dance, Food, Store, Tower, Door, Roof, Stairs, Garden, Chair, Circus

Idea No.	Used Hint	New Function

Sheet 2. Task sheet for experiment with structured and random hint words

4.2. Experiment Results & Discussion

The evaluation items are the quantity and diversity of ideas generated. As an evaluation of quantity, the number of ideas was counted, and t-Test was carried out between Groups. As an evaluation of diversity, the number of functional fixated ideas counted and their portion was calculated. Cases that are directly related with storage are categorized in functional fixation. All functions except above standard on fixation or concrete examples are categorized in outside of fixation. The following ideas, which are came up with this experiment, are categorized in outside of fixation : use as a self feeder, flowerpot using capillary phenomenon, newsstand, water jug, pitcher, hanger joining (to cut into small rectangular shape, pierce two holes and connect hangers), substitute of zipper bag, paper cup cover, business card container, rice container, water purifier (for water tank), booby trap and so on. The following table 1 is a summary of results.

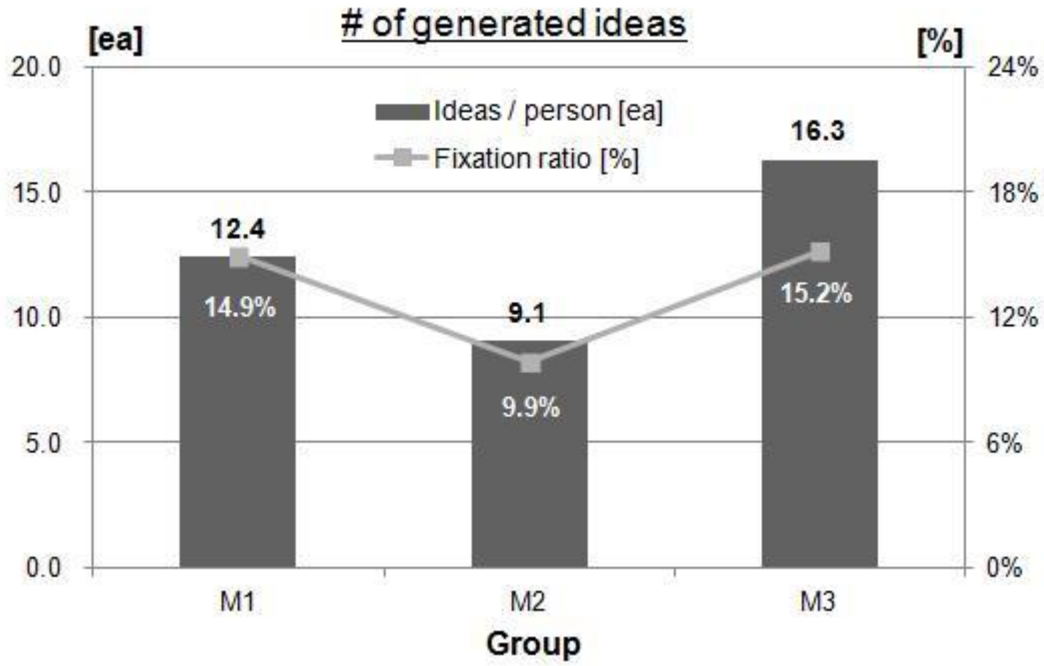


Figure 2. Experiment : The amount of ideas and degree of functional fixation

Table 1: Experiment : The amount of ideas and degree of functional fixation

Group	M1	M2	M3
Participants	41	39	23
Total Ideas	509	354	375
Ideas / Person (Stdev.)	12.4 (5.7)	9.1 (3.9)	16.3 (5.3)
Fixed Ideas	76 (14.9%)	35 (9.9%)	57 (15.2%)

Note. M1 = Group 1 (Free-association), M2 = Group 2 (Conventional analogical reasoning), M3 = Group 3 (Hybrid analogical reasoning)

At first, the order of idea generated is M3 > M1 > M2. The difference between M1 and M2, M2 and M3, M1 and M3 are significant ($p<.05$). While M2 was given a hint sheet for idea generation, their amount is still lower than M1's. This result implicates that given source words may cause constraints on idea generation (Smith et al., 1993). Secondly, comparing the control groups with the experimental group, M3 (Avg.=16.3, Stdev.=5.3) shows a significantly better performance (4~7 more ideas) in comparison with M1 & M2 ($p<.05$ & $p<.05$). This is an interesting result. Despite M2 and M3 being given the same hint sheet, M2 exhibited smaller outcome compared to M1. Also, M3 had better performance when compared to M1 and M2. These results support an effect of procedural aspect in hybrid analogy. That is, mixed thinking may boost an increase in quantity, and improve utilization of a source. Thirdly, the order of fixed idea ratio is M1 = M3 > M2 (see Table 1). That is, participants of M1, M3 showed functional fixation heavily. In addition, though participants of M2 generated a smaller the number of ideas than M1, they showed bigger deviation from functional fixation than M1. This shows the role of a source in analogical reasoning. On the other hand, participants of M3 showed worse performance comparing to the M2. Functional fixation rate of M3a (the first 7.5 minutes with no hints, 19.3%) was as high as M1 (with no hints, 14.9%). Portion of functional fixed ideas of M3b (the last 7.5 minutes with hints, 7.6%) was as low as M2 (with hints, 9.9%). In summary, these results implicate that providing a source initially for idea generation may cause a constraint on amount. Hybrid analogy method (i.e. providing source after enough free association) helps to increase quantity, and affects to deviate from functional fixation only when hints were given. Consequently, in views of both of quantity and quality, the present study supports the hypotheses of this study and effects of hybrid analogy.

6. Conclusion

Experiment was conducted with divergent thinking task – finding new function of specific object. As a result, hybrid analogy groups produced more (and diverse) ideas than those of control groups. Providing source initially causes constraints on idea generation. But experimental results implicate that source of idea generation may take an advantage when it is used after enough free-willing thinking. In conclusion, double mixed method – i.e. the mixed sequence of idea generation stage & the mixed idea generation source – is the improved method than existing idea generation methodologies. And this study supports it through experiment (Ryu, 2013).

References

1. Altshuller G. S. (1979). Creativity as an exact science. Moscow: Sovietskoe radio.

2. de Bono, E. (1970). Lateral thinking: Creativity step by step. New York: Harper and Row.

3. de Bono, E. (2008). Creativity workout: 62 Exercises to Unlock Your Most Creative Ideas

4. Dunbar, K. (1995). How scientists really reason: Scientific reasoning in real-world laboratories.

In R.J. Sternberg&J. Davidson (Eds.), The nature of insight (pp. 365–395). Cambridge, MA: MIT Press.

5. Gentner, D., & Markman, A. B. (1997). Structural alignment in analogy and similarity. American Psychologist, 52, 45–56.

6. Gonzalez, D. (2001). The art of solving problem

7. Guilford, J. P. (1986). Creative talents: Their nature, uses and development. Buffalo, N.Y.: Bearly.

8. Hampton, J. A. (1987). Inheritance of attributes in natural concept conjunctions. Memory & Cognition, 15, 55-71.

9. Heath, C., Larrick, R.P., & Klayman, J. (1998). Cognitive repairs: How organizational practices can compensate for individual shortcomings. In B.M. Staw & L.L. Cummings (Eds.), Research in organizational behavior, 20. 1–37.

10. Martindale, C. (1989). Personality, situation, and creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), Handbook of creativity: Perspectives on individual differences (pp. 211-232). New York: Plenum Press.

11. Mumford, M. D. (2003). Creativity Research Journal, 15, 107–120.

12. Pink, D. (2006). A whole new mind : Why Right-Brainers Will Rule the Future

13. Ryu, M. S. (2013). The improvement of ideation by hybrid-metaphorming

14. Simonton, D. K. (1999). Origins of genius: Darwinian perspectives on creativity. New York: Oxford University Press.

15. Smith, S. M., Ward, T. B., & Schumacher, J. S. (1993). Constraining effects of examples on a creative generation task. Memory & Cognition, 21, 837-845.

16. Stanovich, K. E. (2009). What intelligence tests miss: The psychology of rational thought.

New Haven, CT: Yale University Press.

17. Ward, T. & Kolomytz, Y. (2010). Cognition and creativity. In J. Kaufman & R. Sternberg, (Eds.),

Cambridge Handbook of Creativity (pp. 93-112). Cambridge UK: Cambridge University Press.

18. Ward, T. B., Patterson, M. J., & Sifonts, C. M. (2004). The role of specificity and abstraction in creative idea generation. Creativity Research Journal, 16, 1-9.

19. Weisberg, R. W. (1995a). Case Studies of Creative Thinking: Reproduction versus Restructuring in the Real World. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), The creative cognition approach (pp. 53-72). Cambridge, MA: MIT Press.

20. Welling, H. (2007). Four mental operations in creative cognition: The importance of abstraction.

Creativity Research Journal, 19, 163-177.

21. Wertheimer, M. (1945). Productive Thinking. New York: Harper.

22. Wertheimer, M. (1991). Max Wertheimer: Modern cognitive psychology and the Gestalt problem in . A. . Kimble, M. Wertheimer, & C. White (Eds.), Portraits of pioneers in psychology (Vol. 1, pp. 189-207) Hillsdale, NJ: Lawrence Erlbaum.

23. http://en.wikipedia.org

Author (co-author) to contact: Cheol Woong Kim, cheolwoong.kim@sk.com

TRIZfest 2014

Case Study with TRIZ: Allocation System for a Processing Machine

Dipl.-Ing. Horst Th. Nähler[a], Dipl.-Kulturwiss. Barbara Gronauer[b]

[a]*c4pi – Center for Product-Innovation, Hünfeld, 36088, Germany*

[b]*StrategieInnovation, Hünfeld, 36088, Germany*

Abstract

This case study presents the new development of an allocation system by using TRIZ tools.

The allocation of sheet metal parts for further treatment is currently done manually. The demand for decreasing station times to utilize the processing machine to its full capacity brought up the need for a partially automated allocation system. Because of the high requirements regarding process reliability, safety, robustness, maintainability and asset costs, a systematic approach using TRIZ tools was necessary for developing a successful solution.

The development process of the allocation system was systematically conducted using several TRIZ tools. The first step covers the clarification of the task, the customer requirements and specific company guidelines. Then analytical tools of TRIZ were used to structure the task and identify key problems and development obstacles. After that, TRIZ solution tools were utilized to develop ideas which were finally combined into a qualified, capable solution.

The presentation shows, how TRIZ tools sped up the process of task analysis, problem identification and solution generation significantly. The developed concept is currently in the feasibility and design phase, main secondary problems are as well tackled with TRIZ tools. Prototype testing and implementation is planned for later this year.

Keywords: TRIZ Case Study, Systematic Product Development, Automation, Allocation System, Sheet Metal Processing.

1. Initial Situation

1.1. Project Background

The case study that is represented here is a current development project of a German Small Enterprise that is specialized in developing and building special purpose machinery. For this paper, the company will be called GSE. Because of the actuality of the project and existing non-disclosure agreements names, details, numbers, sketches and drawings have been modified and generalized. The project is still ongoing while this paper has been written and is scheduled to be finished later in 2014.

The project was supported and accompanied by Barbara Gronauer, StrategieInnovation, and Horst Nähler, c4pi. As accredited MATRIZ Level 3 trainers, they were asked to support the development team by using methods and concepts of TRIZ to speed up the development process and solution finding for development tasks and obstacles.

TRIZ was used on different levels during this project:

1. Structuring the approach of the development task,
2. Establishing a common language among the developers,
3. Enhancing the analysis of problem situations and
4. Enabling focused solving of the “right” problems.

The project was initiated by a customer of GSE, who are producing sheet metal parts of different sizes. During the manufacturing process, metal sheets are formed in presses. The formed raw parts then have to be processed in processing machines. Currently, one press supplies up to 6 processing machines with one worker supplying two processing machines. The processing takes up to 90 seconds which leaves enough time for the worker to manually place a raw part into the fixture of one processing machine and during processing to remove the finished parts and clean the fixture of the second machine, which is then fed with another raw part (see Fig. 1). In this setting, the long processing time in the processing machine is the bottleneck of the production flow.

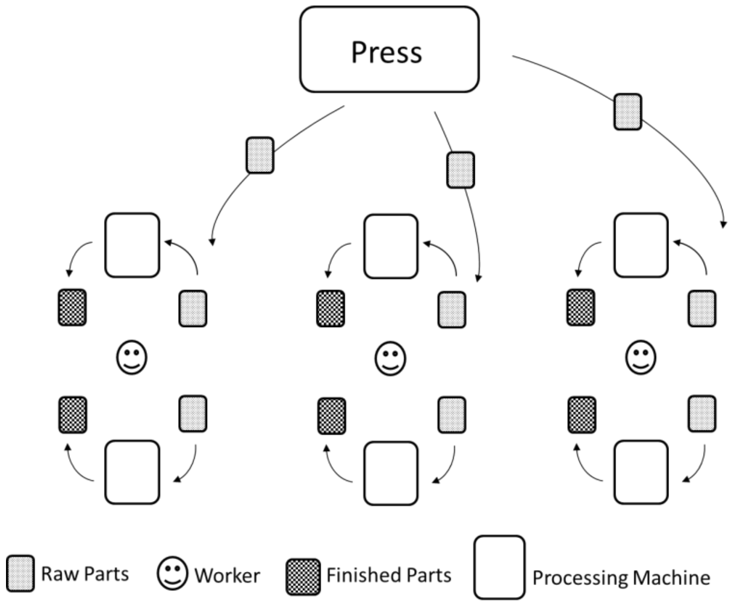


Fig. 1. Initial situation of the manufacturing process

As a result, the customer of GSE intends to significantly increase production output by replacing the processing machines with new ones which are capable of cutting the processing time in half. As a result, the worker becomes the bottleneck and the whole process becomes more prone to human error and variations in productivity of the worker.

So a (semi-) automated solution is desired which uncouples the allocation / supplying process from the processing itself by providing a cache for raw parts which on one end is easy to load manually by a worker and which can on the other end be off-loaded by a robot capable of quickly and accurately placing the raw parts into the fixture of the processing machines as well as taking out the finished parts (see Fig. 2).

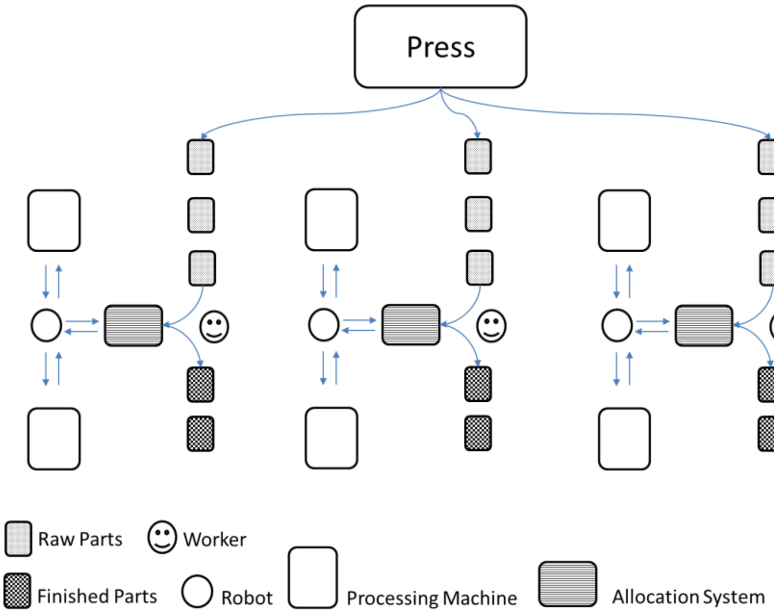


Fig. 2. Desired workflow with semi-automated Allocation System

GSE was asked to develop this allocation system within the conditions of the production process, which cannot be changed. The allocation system must be able to reduce cycle times by 50%, does not generate risk of injury for the worker, is robust within the production environment (dust, abrasive particles) and does not need extensive maintenance effort. Further requirements and criteria are the targeted costs for the allocation system, reliability of the system, energy usage and consumption of supply materials (e.g. compressed air, lubrication).

1.2. Situation Clarification

TRIZ was introduced into the development process at a time, where a rough concept for the allocation system was already at hand. Nevertheless, most customer requirements were still unknown, fuzzy, differing throughout subject matter experts and generally subject to change, so it was a typical business situation.

The first task was to clarify the initial situation and known facts/requirements. The TRIZ-tool chosen was the multiscreen approach [3] [6]. With this approach the team was able to look at the structure of the system to be developed, its environment (Supersystems) and its current sub-assemblies (Subsystems). Furthermore, by including the timeline (Past-Present-Future), the team was enabled to systematically assess the reasons for the change from the “old” production process to the current or planned process as well as estimating changing conditions in the future which might affect current design decisions.

As a result of using the Multiscreen-Scheme, the team was able to gather available information, generate substantiated estimations and bring all this into a structured form in a short amount of time. Based on the Scheme decisions could be made affecting the design of the allocation system with regard to future requirements while making sure that current requirements are being met. The Multiscreen Approach worked as a catalyst in bringing together the knowledge of the team members and focusing their thoughts and estimations [2].

1.2.1. First Step: System – Subsystems - Supersystems

In the first step of filling the 9 Screens the team looked at the current stage of development and the intended design of the allocation system (see Fig. 3). The system is allocation system, consisting of a guide, rack, lift, camera, control system and transport boxes. The

Supersystems identified were the upstream press, raw parts, finished parts, worker, robot and downstream processing machines.

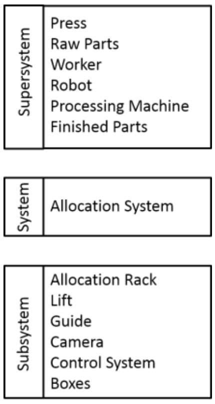


Fig. 3. System-Structure of the Allocation System

1.2.1.1. Functionality of the System

As mentioned before, the allocation system consists of an allocation rack which holds a specified number of transport boxes. These transport boxes contain raw parts and finished parts and allow the inflow and outflow to and from the processing machine on stacked levels.

On the loading end the system features a guide that allows a controlled flow of the boxes to and from the rack to the point where the worker is loading/unloading the parts. The offloading end has a lift system that is bringing the boxes to the required floor of the rack and positions the boxes to allow the loading/offloading of parts by the robot. Furthermore, an image recognition system is used in conjunction with the robot to allow accurate gripping of the parts.

A schematic sketch of the allocation system is shown below (see Fig. 4).

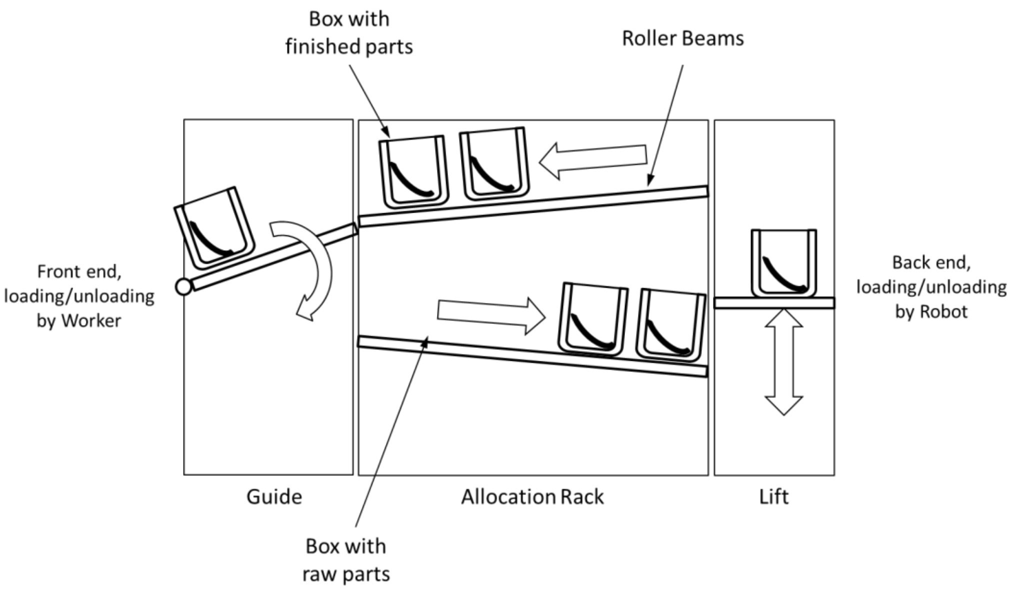


Fig. 4. Simplified representation of the Allocation System, first concept

1.2.2. Second Step: Past – Present - Future

After structuring the current system design and raising awareness for the Supersystem requirements and boundary conditions, the history of the system was assessed. In the past, the processing machines were loaded and unloaded manually by a worker. Other than that, the process worked similar. It is also recognizable that the system development follows the Trends of Engineering System Evolution with respect to decreasing human interaction [8]. In the past, the worker was the system delivering all the functions necessary from placing the raw part and removing the finished part (energy source, transmission, tool, control system [1] [3] [9]), while in the current design the worker is already partly disconnected from the process. The accurate placement of the raw parts is now more efficiently done by a robot and automated control system.

	Past	Present
Supersystem	Press Raw Parts Worker Processing Machine Finished Parts	Press Raw Parts Worker Robot Processing Machine Finished Parts
System	Allocation operator	Allocation System
Subsystem		Allocation Rack Lift Guide Camera Control System Boxes

Fig. 5. Past and Present System

While discussing about the future it was clear that the worker will be replaced by another loading robot on the front end of the allocation system to create a fully automated process. During this discussion the development team identified requirements resulting from that future scenario and how to detail the system today to be prepared best for future changes (see Fig. 6).

	Past	Present	Future
Supersystem	Press Raw Parts Processing Machine Finished Parts	Press Raw Parts Worker Robot Processing Machine Finished Parts	Press Raw Parts Robot 1 Robot 2 Processing Machine Finished Parts
System	Allocation operator	Allocation System	Allocation System
Subsystem		Allocation Rack Lift Guide Camera Control System Boxes	Allocation Rack Lift Guide Camera Control System Boxes

Fig. 6. Multiscreen assessment of Allocation System

With this preparatory analysis done, the team could decide on which level the most significant tasks are and which problems and obstacles to tackle first. It could be made clear that the further detailing of the allocation system had top priority and that the interfaces between the robot and processing machines had to be addressed later. So the decision was made to use

TRIZ to further analyze the allocation system and the tasks arising from the client's requirements.

2. Problem Analysis

Following the TRIZ process a thorough problem analysis is necessary to identify main problems, build relevant problem models and chose applicable solution models and solution strategies.

First, a function model of the allocation system was built. Even at this early stage, the components chosen as the general structure of the system could be used to sufficiently model the system with its interactions. During this process all team members agreed upon the terms used and the syntax of the TRIZ Function Analysis made it easy to communicate on a general level free of specialized expert's jargon. The first function model was aimed at representing a functioning system, free of disadvantages.

In the second step, function disadvantages have been added that represent current development obstacles and shortcomings of the current concept. By discussing these topics within the syntax of the Function Analysis, the problems could be objectified and the focus could be laid upon harmful, insufficient and excessive interactions between the components of the function model.

After including the function disadvantages into the function model, each disadvantage was assessed, for some a Cause and Effect Chain Analysis (CECA) has been conducted. The assessment brought up several contradictions which have been addressed subsequently in the Solution Phase.

2.1. Function Model of the Allocation System

According to the rules of TRIZ Function Analysis [3] [8], the main function of the Allocation System was formulated as "Allocation System stocks Parts" and "Allocation System moves Parts". The interactions of the components have been formulated. Only the graphic representation of the function model is shown here, Component Analysis, Interaction Analysis and the Tabular Function Model are not explicitly shown.

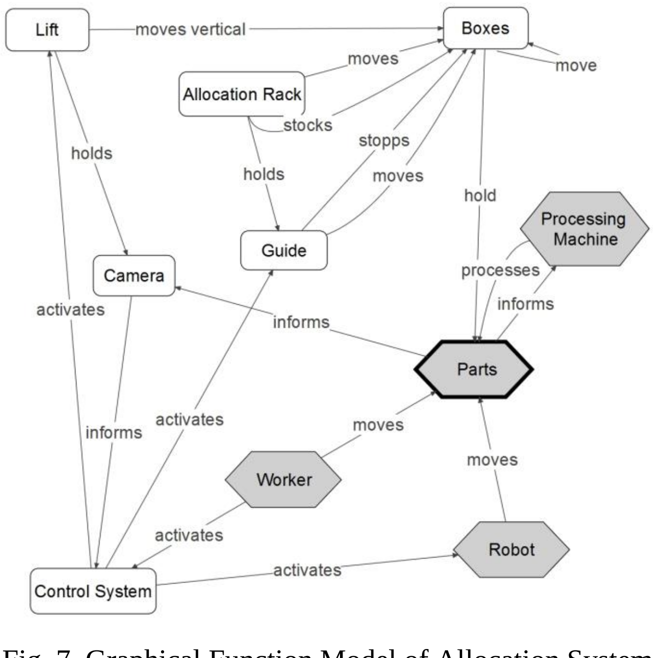


Fig. 7. Graphical Function Model of Allocation System

Based on the function model above, Function Disadvantages have been formulated to represent the problematic areas within the system. The most important factor was the safety of the worker. Due to legal regulations the system must under all circumstances provide safe and secure working conditions. The risk of injury due to moving parts has to be eliminated. Also, specified limits for noise emissions have to be met.

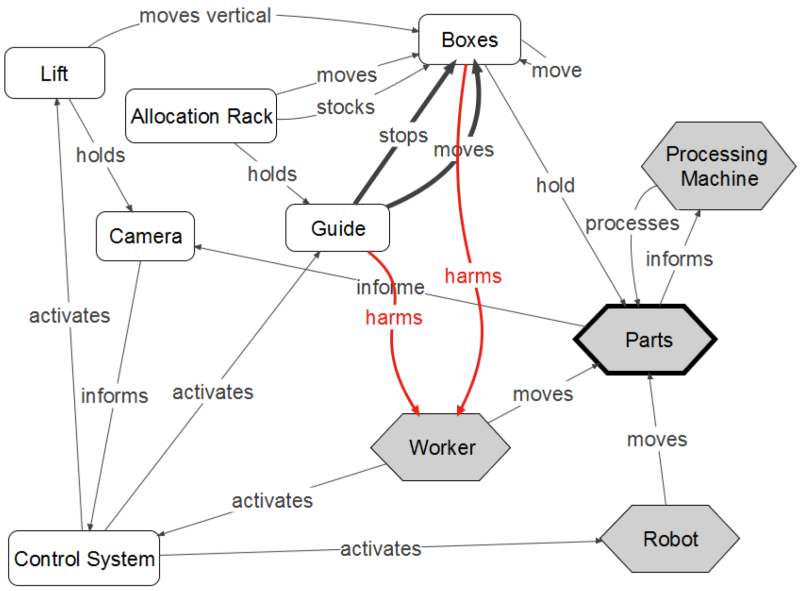


Fig. 8. Function Model with Function Disadvantages

Four function disadvantages are exemplarily shown in the Function Model in Fig. 8:

1. Guide stops Boxes excessively

This disadvantage depicts the situation that the boxes, due to their weight and the angular positioning of the guide, have a high velocity that leads to an abrupt impact. This impact generates noise and represents a potential threat to the worker.

2. Guide harms Worker

The guide consists of moving parts to be able to direct the boxes into different levels of the allocation rack. These moving parts are positioned in the area where the worker has to load and unload parts. Therefor the threat of injury is given and has to be eliminated.

3. Boxes harm Worker

As mentioned under 1. the boxes are able to hit the worker due to their kinetic energy. A hand can potentially be placed between parts of the guide and the moving box.

4. Guide moves Boxes excessively

Due to the high angle of the guide the boxes are accelerated to a high velocity, leading to high kinetic energy and thus being a risk for the worker.

2.2. CECA

To uncover the key problems the disadvantages have been further analyzed using the Cause and Effect Chain Analysis. Starting with the apparent problem of the worker being harmed, cause and effect chains have been developed.

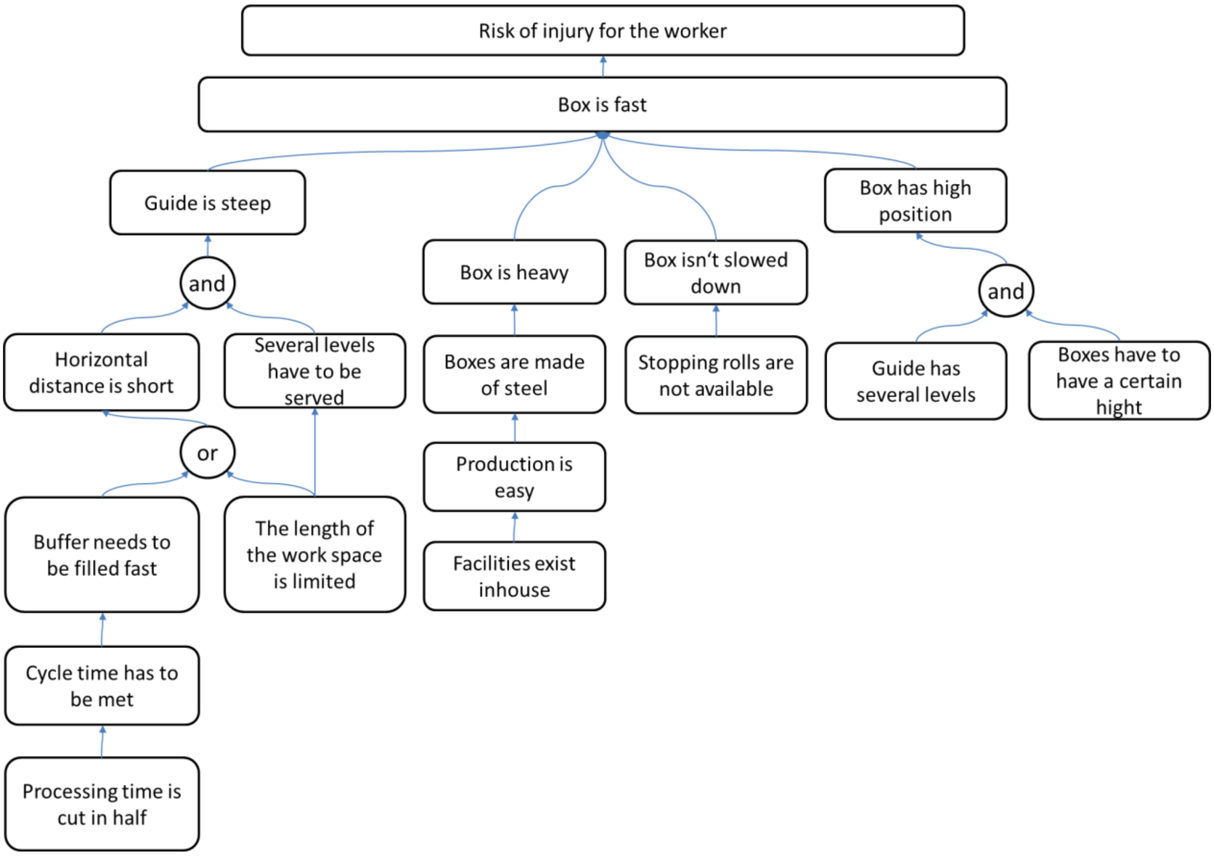


Fig. 9. Cause Effect Chain Analysis for Risk of Injury

Additionally, the „Operation Zones" [2] have been identified where injuries could happen. Exemplarily, these are at all edges where the sliding surfaces of the boxes change their angle relative to each other. Due to this change in angle, a gap is forming where a worker might place his hands and be injured.

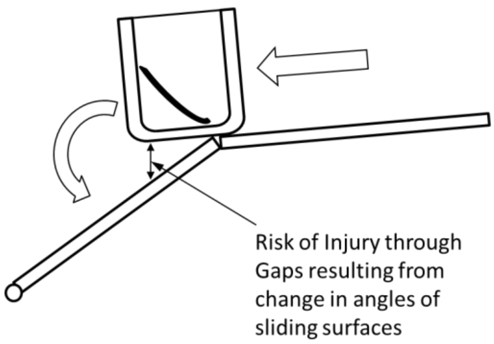


Fig. 10. "Operating Zone" where the problem occurs

3. Formulating Problem Models

In the discussion around the causes and effects of each disadvantage, some ideas have been generated. Nevertheless, each idea was attached to subsequent disadvantages, so that engineering contradictions could be built starting with "initial ideas" that would lead to improvement in one aspect but also lead to deteriorating other factors. Some of the contradictions are listed below.

3.1. Primary Problem: Worker's Health and Safety

According to the first design concept, the boxes containing the parts were designed to slide on roller beams through their own weight and the angular positioning of the guide and allocation rack levels. Preliminary tests showed that the boxes were really picking up speed along the length of the allocation rack. This high velocity poses a risk for the worker (see also CECA). So the use of boxes was questioned and several options were discussed.

Additionally, the use of a second lift instead of a guide on the front-end of the Allocation System was discussed to have a more controlled movement of the boxes and eliminating changes in sliding path angles (and eliminating gaps), thus reducing the risk of injury.

The thought process was supported by the concept of Ideality, always looking for possibilities of functions being carried out by "itself" or looking for the ideal system (e.g. the ideal box), that is performing the useful functions without being present physically [3] [5] [6].

Some of the contradictions formulated are shown below.

3.1.1. Engineering Contradictions resulting from using a brush belt conveyor

One of the initial ideas was to use a belt conveyor to move the parts inside the allocation rack, replacing the steel boxes. The conveyor belt should feature bristles with different lengths to hold and separate the parts. Nevertheless, some disadvantages are linked to this initial idea, resulting in formulating the following contradictions:

If	we use a brush belt conveyor
Than	the safety is higher
But	a power drive is neccesary
If	we use a brush belt conveyor
Than	the weight is low
But	a power drive is neccesary

3.1.2. Engineering Contradictions regarding using Boxes and using Lifts

If	we use boxes
Than	the system is simple
But	the weight is high
If	we use boxes
Than	the parts have a defined space
But	the weight is high
If	we use boxes
Than	the movement of the parts is easy
But	the risk of injury is higher

If	we use two lifts
Than	we have a high functionality
But	the mechanical effort is high
If	we use two lifts
Than	we have no edges
But	the mechanical effort is high
If	we use two lifts
Than	the worker is save
But	the mechanical effort is high

From these If… Then… But… formulations, Parameters could be extracted to make clear which generalized aspects are in conflict with each other. Inventive Principles were then taken from the Contradiction Matrix 2010 [4] to take a prioritized look at successful strategies dealing with the conflicting aspects of the problem situation.

If	we construct our system without a second lift (guide)
Than	we have a simple system → Parameter: Complexity (Nr. 45)
But	we have more edges, too. → Parameter: Risk of Injury/Safety (Nr. 38)

Innovative Principles:
28 Mechanics Substitution
05 Merging
24 Intermediary
10 Preliminary Action

3.1.1. Physical Contradiction representing Worker Safety and Cycle Time

Based upon the assessment of the situation using CECA and Engineering Contradictions, the following Physical Contradiction could be derived to formulate the heart of the problem regarding the usage of steel boxes and its resulting risk of injury.

If	we stopp the boxes
Than	the safety of the worker increases
But	the cycle time will be to long

The boxes
should be moving fast to reach a short cycle time and
should be standing still to ensure a save work situation

First it was stated that the boxes need to be stopped or slowed down to increase worker safety. But slowing down also means an increased cycle time, which is unacceptable. Not shown is the inverted Engineering Contradiction, stating that if the boxes are sped up, the cycle time increases, but the worker's safety deteriorates.

The Physical Contradiction could easily be derived from this statement, enabling a focused idea generation around this inventive problem.

4. Solution Concepts

After the problem models were formulated, the idea generation phase was initiated. Using suggested Inventive Principles and Separation Principles, the initial concept of the allocation system was modified to overcome the contradictions coupled with the first draft.

4.1. Solution Concepts for Worker's Health and Safety

Guided by the TRIZ solution strategies and principles, several ideas were sparked and developed into the following concept:

By separating the need for fast moving boxes and still boxes in time, an enclosed solution was developed that only allows the worker to access the loading / unloading area when all moving parts have come to a full stop. The solution suggests a sliding door that is opened by a counterweight (ideally "opening itself") as soon as a box is ready to be loaded / unloaded. After the worker completed his step, he closes the sliding door, activating the Allocation System and allowing the boxes to move fast through the steep guide and allocation rack. This results in lower cycle times while eliminating the risk of injury. Another advantage of an enclosed system is that noise can be effectively damped and no special dampers are necessary to reduce impact speed of the boxes.

As a second winning concept, the moving principle for the boxes was changed from sliding on roller beams to attaching rolls to the boxes themselves. In a first idea, rollers were suggested on the bottom of the boxes, but during the idea generation phase and the discussion this concept was changed to a roller-and-track system, where rollers are placed in the top corners of the boxes, which can then be hanged into a track system that is guiding the boxes throughout the allocation system.

This concept also enabled the elimination of a driven belt on the back-end of the allocation system which was before necessary to move the boxes in and out of the lift. The roller-and-rail system allows the boxes to move themselves into and out of the lift. Small gaps and angular changes in the track can easily be rolled over.

The roller-and-track system then has been optimized to be self-cleaning by using shaped rollers that run on guiding rails. Dust from the environment will first be significantly reduced by the casing of the enclosed system, additionally dust is very unlikely to settle on the rails.

4. Conclusion and further Steps

The support of the development project with TRIZ resulted in the intended advantages. The time used for thoroughly analyzing the situation, identifying the major problems and focusing on root causes instead of symptoms paid off in the following process. Results and information were effectively generated in a short amount of time, leading to sound design decisions that were robust, safe and cost effective.

Currently, the concept is detailed. Subsequent problems are if necessary also tackled with TRIZ tools. Tests of the roller-and-rail system are currently going on and the first prototype run is scheduled to be completed in the first half of 2014. The delivery of the first allocation system is planned for end of 2014.

Upcoming development tasks for future versions are already being identified, one of them being to decrease the overall length of the allocation system to reduce the occupied space on the shop floor. It is intended to establish TRIZ as an integral part of the development process of the company. Until now, 4 members of the company have already been trained and granted the MATRIZ Level 1 certificate.

References

1. Altschuller G. S. Erfinden Wege zur Lösung technischer Probleme, Hrsg. Prof. Dr. Martin G. Möhrle, Cottbus, 1998 PI

2. Altshuller G.S. The Innovation Algorithm translation by Lev Shulyak and Steven Rodman TIC, Inc. 2000

3. Hentschel C. Gundlach C. Nähler H. TRIZ Innovation mit System Carl Hanser Verlag 2010

4. Mann D. Matrix 2010 Re-Update der TRIZ Widerspruchsmatrix translated by Horst Nähler, Elisabeth Brilke, Hrsg. Horst Nähler, Barbara Gronauer, Carsten Gundlach 2013

5. Nähler H. Reiffenscheid C. Schnittker F. TRIZ IT! Der TRIZ Leitfaden Terex Corporation 2012

6. Koltze K. Souchkov V. Systematische Innovation Carls Hanser Verlag 2011

7. Gundlach C. Nähler H. Innovation mit TRIZ Konzepte, Werkzeuge, Praxisanwendungen symposion Publishing 2006

8. Training Material TRIZ Level 3 Certification Training MATRIZ 2006, 2010

9. Ivanov G. Formulas of Creativity Hrsg. Dr. Robert Adunka 2013

Author (co-author) to contact: Horst Th. Naehler, naehler@c4pi.de

TRIZfest 2014

Development of a Plastic Recycler Applying TRIZ

Christopher Münzberg, Hubertus Heigl, Phillip Schrieverhoff, Udo Lindemann

Institute of Product Development (Technische Universität München), Boltzmannstr. 15, 85748 Garching, Germany

Abstract

This paper presents the development of a plastic recycler for rapid-prototyping (RP) machines with the support of TRIZ. A major cost factor of today's RP-machines is the filament, which is the base material for the production of the prototype models. Inside the RP-machine the filament is fused and then printed in layers to produce 3D-models. Since the cost of purchase of RP-machines is on the way to be dramatically reduced with the help of an open-source soft- and hardware program called RepRap, the filament is one of the remaining cost-pushers. The RepRap program provides all the important knowledge, e.g. software programs or design drawings, for building a RP-machine. This allows reducing the cost of purchase of a RP-machine to under € 1,000. One of the mayor advantages of RepRap RP-machines is the self-reproducing aspect of the machines. Major parts of a typical RepRap RP machine can be printed with other RP-machines, which makes it a popular RP-machine for academic and do-it-yourself projects and even more important to have cheap base material available.

The case study of the recycler builds on the RepRap idea. Therefore, one key requirement was the manufacturability of as many parts as possible with RP-machines, on top of the functional requirement to produce a good quality filament out of misprinted models, outdated models, or plastic pellets.

For the recycling two process actions are needed: disassembly of the models (1) and processing of the pellets or shred material to filament (2). A first-generation recycler which is compiled of a shredder and an extruder was developed with the help of product development methods. This recycler was able to produce filament in good quality, but had some major issues. Firstly, the shredder could only break small models. Bigger models or models with high material density could not be shred. Secondly, the feed rate of the filament is unsatisfactorily low.

In the presented study the first-generation recycler was analyzed and improved applying TRIZ methodology. A specific set of established TRIZ methods was assembled. The scope of TRIZ methods reaches from innovation checklist, function analysis to technical contradiction. This paper especially focuses on the function analysis applied during the development. It presents the results of analysis of the first-generation extruder, which led to the identification of the development focus and technical possibilities and alternatives for the extruder. Furthermore the development of the function model is elaborated on. It depicts the changes of components and highlights function integration of components into a single component.

The second part of the paper discusses the application of the chosen TRIZ methods during the project work. Advantages and application obstacles of TRIZ in academic projects are depicted. Additionally, an approach to increase the usability of the TRIZ function analysis is introduced. This approach combines a graphical representation of the observed object with the function model. The advantages of the presented approach and its application is discussed. Finally an outlook of further applications of the extruder is given.

Keywords: case study, function analysis, rapid-prototyping, recycling

1. Introduction & Statement of problem

Goal of the presented case study was to improve a filament recycling unit. The development process followed a TRIZ approach tailored to the boundary conditions of the project. This paper highlights the results from TRIZ function analysis. The established function analysis was further developed, and an graphically enhanced function analysis (geFA) following MÜNZBERG et al. 2014 performed. The remainder of this paper is structured as follows. The Introduction describes RepRap Rapid-Prototyping (RP) and elaborates on the reasons for recycling filament. The first-generation recycling unit, which was improved in the case study at hand, is described. Finally geFA is presented. **Section 2** presents the chosen approach for the development process. **Section 3** presents the results of the application of TRIZ methods for the further development of the recycling unit one the basis of selected components. The function models of the different development levels are presented and the second recycling unit is presented. The last **Section 4** discusses the results of the implementation of TRIZ method in the project work, the application of TRIZ function analysis, and the development of the function models through the development process. The paper closes with a conclusion.

RepRap Rapid-Prototyping

The RepRap idea is: printing your own products with a low-cost rapid-prototyping machine (RP-machines) in order to save money and be creative in modelling new parts. RepRap RP-machines are consisting of as many RP-parts as possible to be largely self-replicable. The RP-machines use fused deposition modelling (FDM) to print layers by placing filament on top of the previous cross section.

As base material the RP-machines utilize printed plastic parts (acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA)) as main components. The RepRap approach allows reducing the cost of purchase of a self-assembled RP-machine to under € 1,000, whereas the RepRap community provides all-important files required for printing and building a RepRap RP-machine online. All information and construction manuals are freely available on the Open Source Community platform and shared among the members [1]. However, the major cost factor of RP-machines is the plastic filament, which is the base material for the production of the prototype models. The cost per one kilogram is between € 25 to € 40, depending on the filament quality and the kind of plastic. Due to the constantly dropping prices of professional and self-made RP-machines, the requirement of reducing the cost of printing is emerging because it is the one remaining key obstacle from really achieving a low cost solution.

Recycling unit

The main targets of filament recycling are the reduction printing costs, utilization of existing resources and environmental sustainability. The major functional requirement of the recycler is to produce good quality filament out of misprinted models, outdated models, or plastic pellets. The manufacturability of as many parts as possible by RP-machines is a requirements following the RepRap philosophy. The current recycling unit consists of two machines displayed in Fig 1. First, a shredder to disassemble large plastic parts into small pieces. Second, an extruder to heat the material and shape the filament as base material for the actual RP-process.

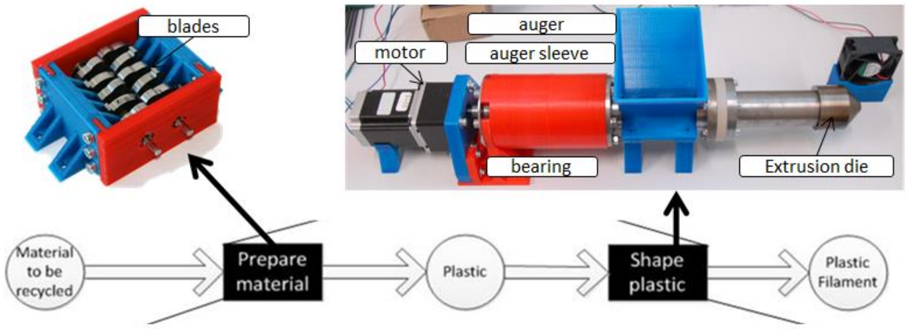


Fig 1. Shredder (left) and extruder (right) assigned to the recycling process steps depicted in a black box model

The shredder has ten contra-rotating cutting blades which are manually driven. With this the introduced material is shred into small pieces. The extruder (cf. Fig 2) forms the shred material into filament. The main parts of the extruder are the auger sleeve which connects the auger with the motor. Attached to the auger sleeve is the bearing of the auger. The augers function is to transport the shred material from the hopper to the extrusion die. The extrusion die heats and squeezes the material to filament.

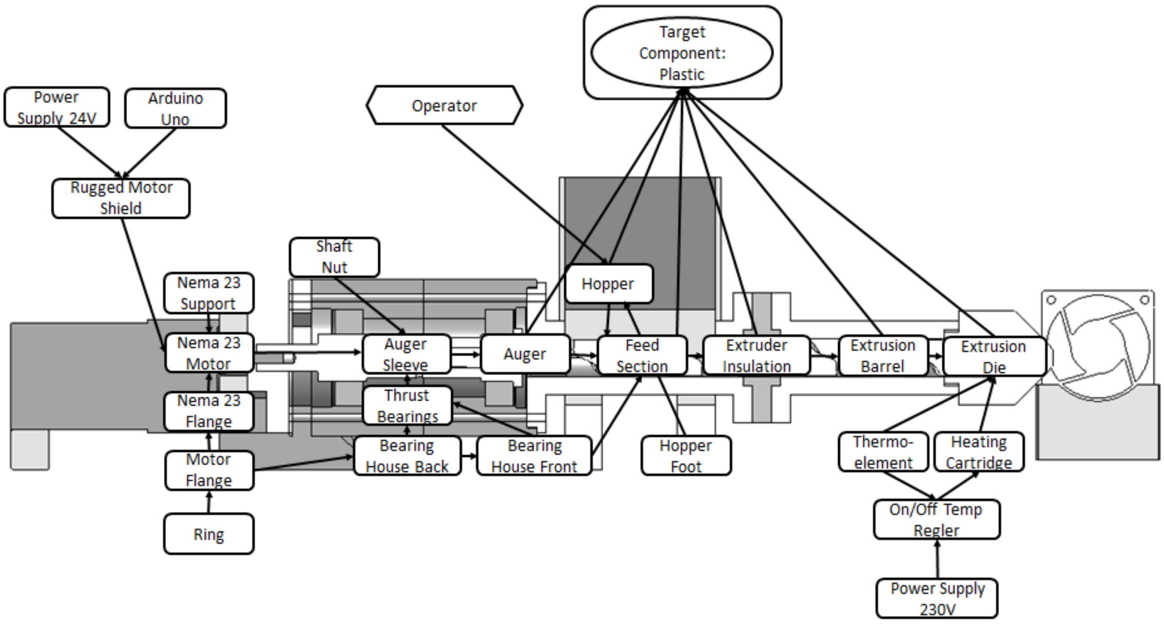


Fig 2. Function model of first generation extruder

The first-generation recycler was developed in a student project following the Munich Procedure Model [2, 3]. It was able to produce filament in good quality within a diameter variation of about 0,02 mm [2, S.40], exhibited some major drawbacks, though. Firstly, the shredder could only break small models. Bigger models or models with high material density could not be shred. Secondly, the feed rate of the filament was only four centimeters per minute [2, S.40]. The goal of the presented case study is to further improve this recycler.

Graphically Enhanced Function Analysis (geFA)

The graphical enhanced function analysis (geFA) approach combines graphical representation of the system with function model. [4].

geFA follows the TRIZ function analysis [5]. It follows three steps:

Step 1: Build TRIZ function model, i.e. fulfill CA, IA, FM

Step 2: Select appropriate system graphic (complete system or detail view)

Step 3: Arrange components corresponding to the system graphic

After setting up the TRIZ function model it is linked to the graphical representation of the system (e.g. cutaway model) and the elements of the model are arranged regarding their position on the graphical representation. The steps of geFA approach are depicted in Fig 3.

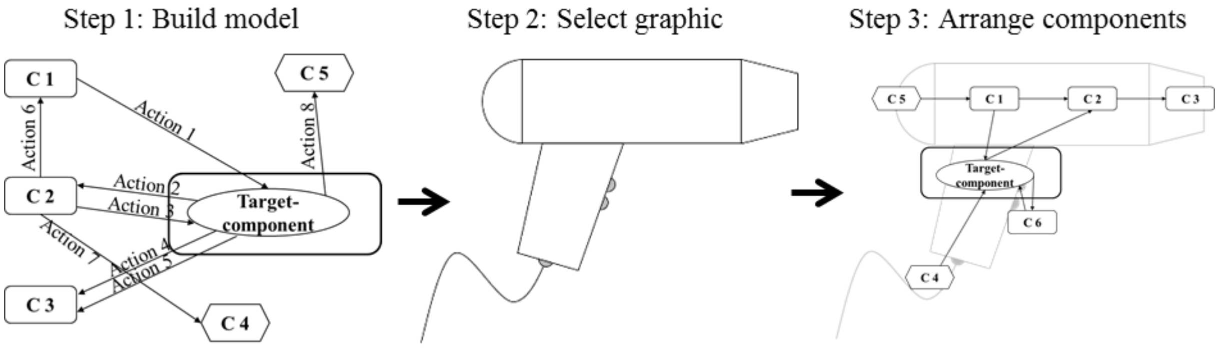


Fig 3. Schematic representation of the graphical enhanced function analysis

The aim of the geFA is to increase on the one hand the interpretability of function models and on the other hand to facilitate the development of a function model. This is achieved by the arrangement of the components as in real life following a cutaway model. Thereby the function model becomes a precious, intuitively understandable platform for discussion of the product functionality and the interaction of the specific components Third parties can understand the model without knowing the function analysis or detailed system knowledge. Equally force and material flux can be displayed more easily.

2. Approach

The further development of the recycling unit presented in Section1 *Recycling unit* followed a TRIZ approach tailored to the boundary conditions of the project. For the selection of this approach a literature research was conducted and the selection of the different TRIZ tools to be applied set up [5, 6, 7, 8]. The initial situation of having a pre-existing product required a different set of tools than the new product development without constraints given for the predecessor. The main focus of attention lay on the beginning of the innovation cycle to achieve a high-level solution based on clear understanding of the current recycler generation and detailed definition of the problems. Throughout the pre-analysis of available tools, methods have been prioritized and applied on the problems. The methods used for the development of the shredder and extruder can be seen in the following Fig 4.

The main target of the presented case study was to improve the existing recycling system. On mechanical level the functionality of the system had to be increased through the improvement of the components, e.g. in terms of a higher a flow-rate of the recycled material. From the manufacturing point of view the cost for the components needed to be reduced and the assembly process had to be simplified. This was done by utilizing TRIZ tools like the 40 Innovative Principles. The TRIZ tools provide the necessary steps for an innovative thinking process for a higher level of inventions. The presented results in this paper focus on the development of the extruder (cf. Fig 1 shape of plastic process) and will bracket out the development of the shredder. TRIZ function analysis (FA) was used as base tool used to depict the discussed problems and was the starting point of the project work. Building up on the FA TRIZ tools like 40 Inventive Principles, Incremental Improvement or Trimming were performed. The selection of the components to be improved was conducted with the help of TRIZ Value Analysis and the Strength Diagram.

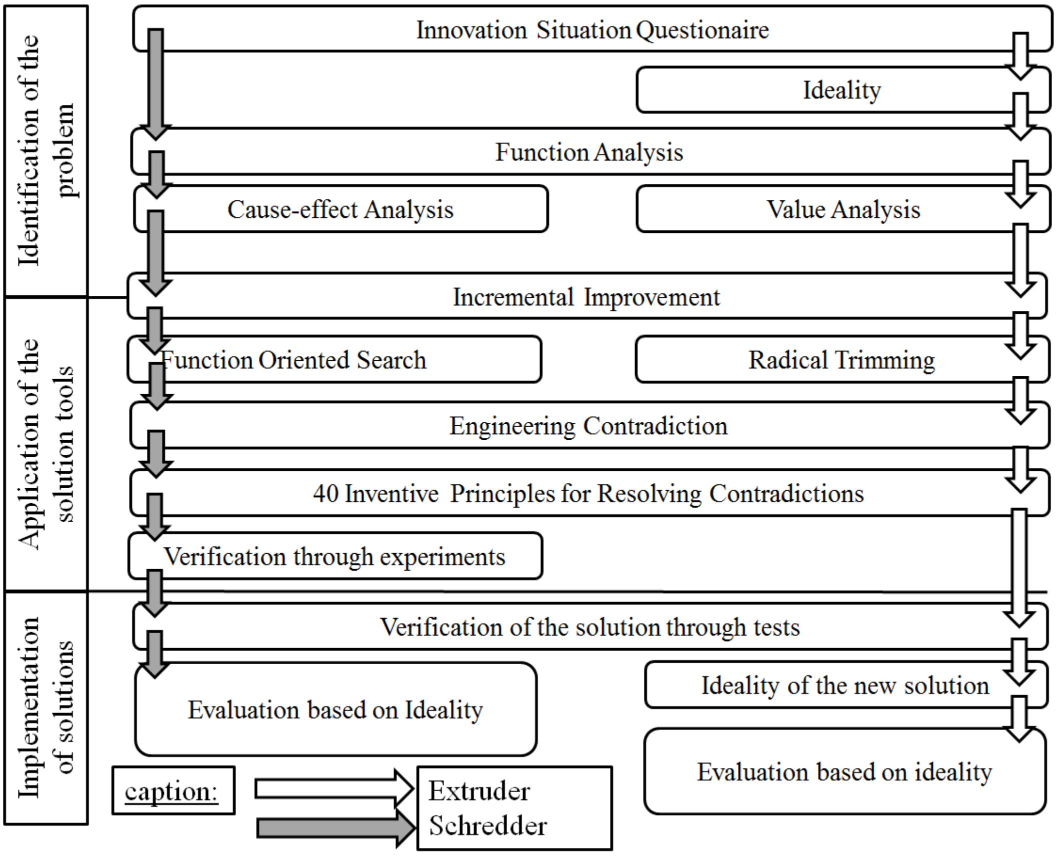


Fig 4. Overview of the chosen TRIZ tools for the development [9]

The strength diagram in Fig 5 discloses different issues with the first-generation extruder, provides recommendations for improvements and tools to be applied helping to solve the problems. The diagram opposes the standardized functionality and cost (material and manufacturing) of the considered components. Thereby, the sectors of the diagram targets different development goals. Components displayed in Sector 2 have a high functionality but also high cost. With this the cost of these components should be reduced. In the case of this case study the components in Sector 2 consists of components made out of steel with relatively high manufacturing costs. The methods applied on this item should help to reduce the amount of expensive steel parts or reduce the costs of them. Sector 3 depicts items with low functionality and high costs. TRIZ trimming should be applied for the depicted components. Sector 4 depicts components with low functionality and low costs. The main target is to improve the functionality by maintaining the costs low. In this case study these components were mainly printed parts or standard parts. Sector 1 is the target sector with high functionality and low cost. One item (Hopper) in the target zone is emphasizing the ideality principle. As a printed part the costs are very low it is in direct contact with the target material (plastic) and values very high in the functionality scoring. With the setup of the strength diagram a general guideline for the improvement of the existing extruder had been defined and the analysis of the individual problems (components) can be applied. geFA helps to keep focused on the technical aspect of questioning throughout the whole process.

3. Application of TRIZ and Results

The second generation of the recycling unit overcomes several issues (feed-rate, continuity of processing, manufacturing costs) of the first-generation. Contradictions were overcome and function integrated through the application of TRIZ tools.

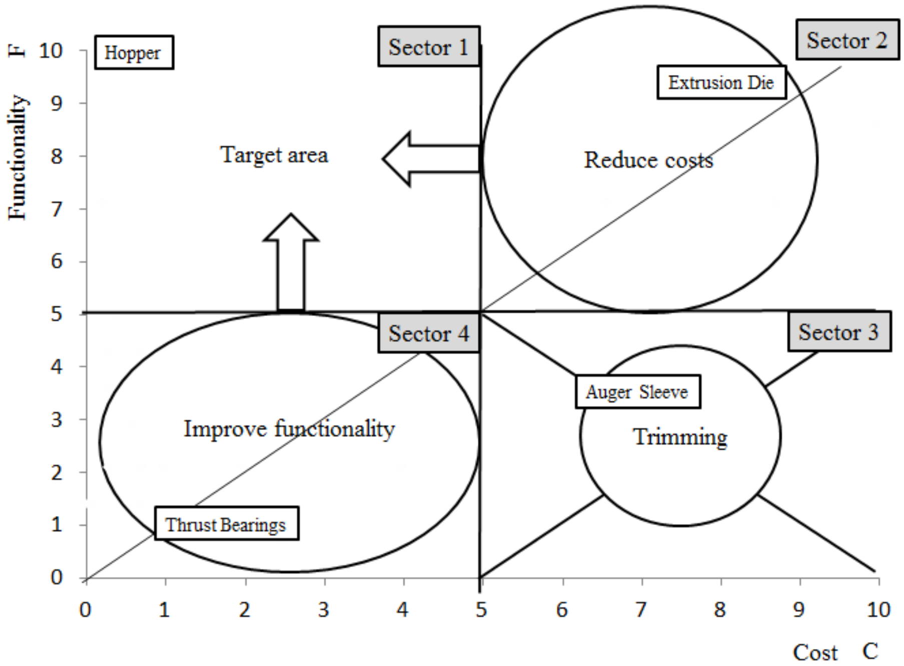


Fig 5. Used strength diagram to selected the components, which had to be further developed [9]

Thereby the value of the device and the Ideality have been improved. This section presents results of the case study, which had the goal to improve the first-generation of a filament recycling unit. Fig 6 shows the final results of the extruder. The shred material is inserted in the extruder via the hopper. The hopper guides the material to the auger. The auger is propelled by the motor and transports the material through the extrusion barrel to the extrusion die. The extrusion die is heated by the heating element and heats the material up to approximately 200°C. The heated extrusion die melts the material. The molten material is squeezed through the extrusion die. This process step forms the new filament. With this the overall filament development process stay the same compared to the first generation described in Section 1.

Starting with this overall description of the further developed extruder three mayor problems are described, which have been overcome with the application of TRIZ are closer described. The considered components are: Auger sleeve and bearing, hopper as well as the extrusion die.

The results are presented in form of function models. First the function model, which describes the problem, is presented. Contrasted to this problem model the function model of the solution is presented.

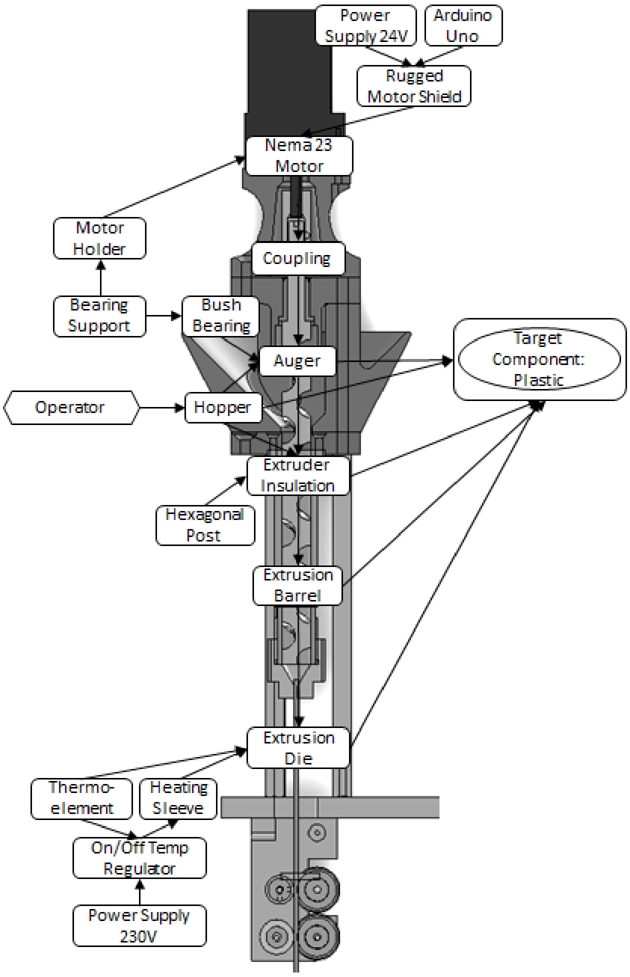


Fig 6. Function model of the second-generation of the filament extruder

Auger Sleeve and bearing

The auger sleeve is connecting the motor with the auger. It provides the smooth surface for bedding the thrust bearings. Due to this structure, it requires additional correlated supporting items like bearing house or shaft nut to fulfil its function (cf. Fig 7 left). The TRIZ value analysis proposed to trim this part (cf. Fig 5). Additionally, TRIZ incremental improvement method was applied. The application of the method revealed that the bearing overachieves its function. Together with the trimming rules (esp. Rule 3: introduction of new functionary) the auger sleeve was trimmed. A coupling, which has a simplified form, and a bush bearing, which is sufficient enough to absorb the introduced forces, was introduced (cf. Fig 7 right). The bush bearing trims the thrust bearing, which led to the overachievement, of the bearing house. For the development of this new solution the TRIZ Innovative Principles (IP) were applied. The following technical contradiction was set up:

IF a smaller bearing is used THEN the construction of the extruder bearing is simplified BUT the loadability of the bearing is reduced.

This contradiction led to the IP 16 (Partial or excessive action) and IP 28 (replacement of mechanical systems with fields). IP 28 led to the bush bearing by changing the complex movable items (balls or cylinders of the bearing) into a simple unmovable principle. The introduction of the bush bearing led to a further improvement of the extruder. The extruder was tilted by 90 degrees from a vertical to horizontal position (IP 17 Transition into a new dimension). With the loads of the extruder could be symmetrical distributed in the system and overall reduction of the load forces was achieved. Additionally, the gravitational force could be used for transport of the shred material inside the extruder.

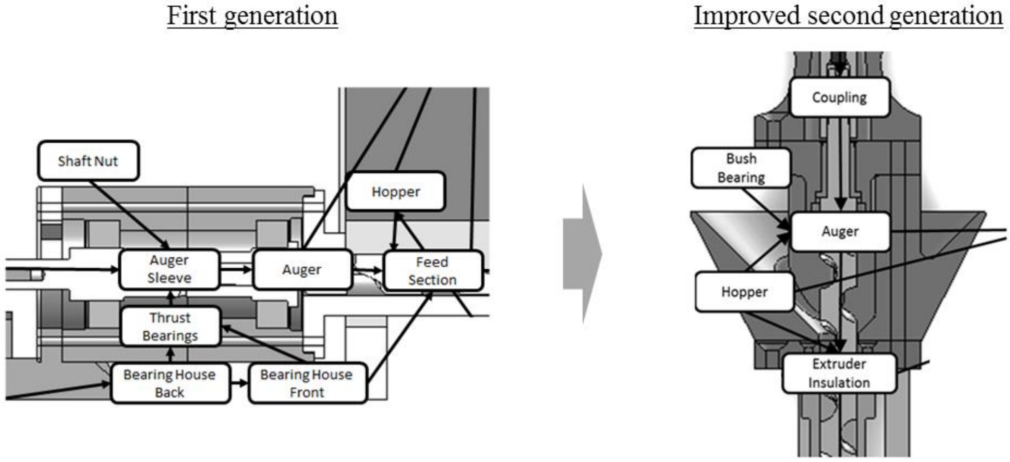


Fig 7. Function models of the bearing unit of the extruder: Auger sleeve with bearing (left); further developed auger sleeve with bush bearing (right)

Overall these developments led to a simplification of the coupling between the motor and the auger. Parts were trimmed, the load forces of the system were reduced and the complexity of the system was reduced through the reduction of parts and the integration of functions.

Hopper

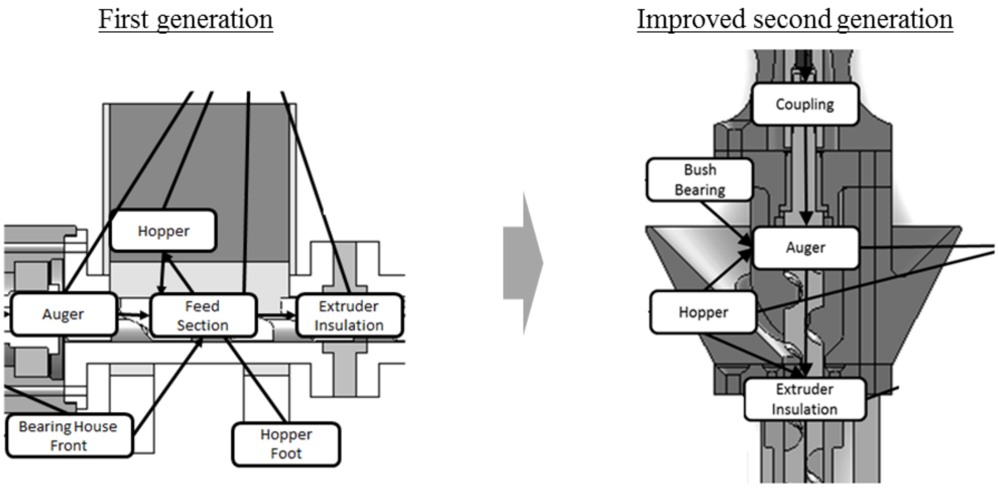


Fig 8. Function models of the hopper: hopper of the first-generation extruder, which mainly serves has an interface between the user and the extruder (left); further developed hopper, which finally presents a core component of the extruder (right)

The main function of the hopper is to gather the material and guide it to the auger (Fig 8 left). The value analysis (cf. Fig 5) showed that the hopper is one of the most important components of the extruder. It has a high functionality and since it is a 3D-printed part it has very low cost. However, through the tilting of the extruder by 90 degrees it functionality can be increased and expensive steel parts, like feed section (cf. Fig 2), can be removed. This leads to a further value increase of the hopper.

The application of IP 28 during the further development of the auger sleeve and thrust bearing let to an upgrade of the hopper. The hopper in the second-generation extruder becomes the core part of the system as depicted in Fig 8 (right). Through the gathering of the shred material it provides the interface between the user and the recycling unit. The new form of the hopper (resulting from the 90 degree tilt) on the one hand holds the extrusion barrel (removal of the hopper foot) and the hexagonal post (posts to hold the extruder). One the other hand it holds the bush bearing and with this the motor. Finally, the manufacturing costs of the hopper are very low since it remains a 3D-printed.

Extrusion Die

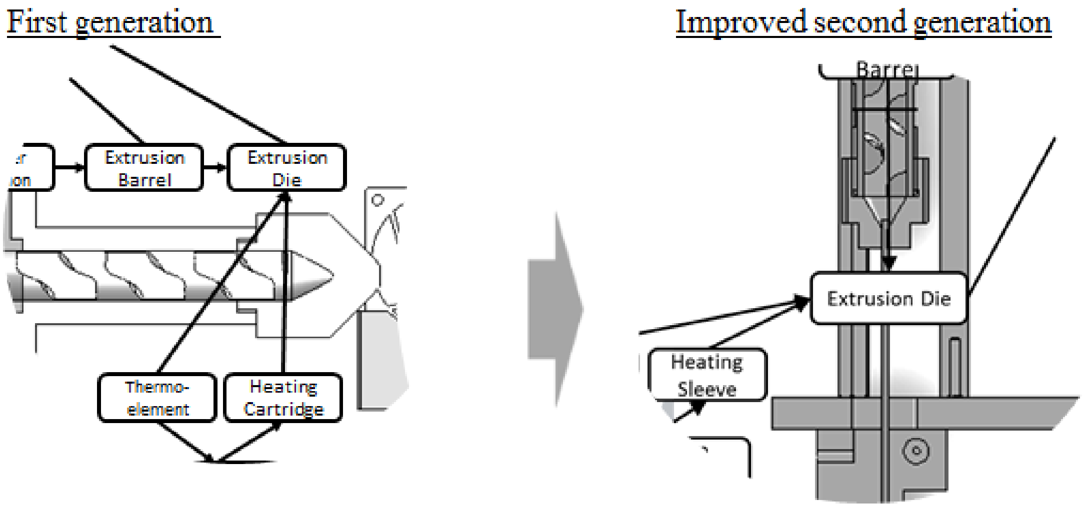


Fig 9. Function models extrusion die: extrusion die with 60 degree opening angle (left); further developed die: extrusion die with 50 degree opening angle (right)

The last presented component is the extrusion die. The die heats the shred material and forms the molten material to the final filament (cf. Fig 9 left). It presents a successful application of TRIZ technical contradiction, which was triggered by the function analysis. The value analysis (cf. Fig 5) revealed that the cost for extrusion die were too high. The high cost stem from the manufacturing process of the die. Since the optimal opening angle of the die for extruders is 50 degrees [Barbier 2013, S.50], electrical discharge machining had been applied for manufacturing. To overcome this problem following technical contradiction was applied:

IF the opening angle of the die is 50 degrees THEN functionality of the die is not optimal BUT the complexity (manufacturing) of the die is reduced.

This contradiction led to IP 16 (Partial or excessive action). The application of this IP led to a new opening angle if 60 degrees, which can be manufactured with standard milling drillers (cf. Fig 9 right). These can obtain in DIY markets. Function test showed that the new extrusion die led to no reduction of the filament quality. With this the cost of the die were reduced and the functionality were maintained and the classification of the extrusion die in the strength diagram moved from sector 2 to sector 1.

Summary of the case study

With the help of TRIZ tools the recycling unit of Barbier [2] was further developed. The system was analyzed with the geFA, a further development of the TRIZ FA. One of the key results was the strength diagram (cf. Fig 5). The diagram targeted the development directions: increase of functionality, reduction of cost, or trimming of components. With the help of the function models Technical Contradictions were established. With the help of the Technical Contradictions and the 40 Innovative Principles solutions were developed and implemented in a second generation recycling unit [9]. The improvement of the three observed components is depicted in Fig 6 – Fig 9. The auger sleeve and bearing were trimmed. The hopper functionality was further increased, and the cost for the extrusion die was minimized. With this the extrusion die moves in the new strength diagram (cf. Fig 10) from Sector 2 to the Target-Sector 1.

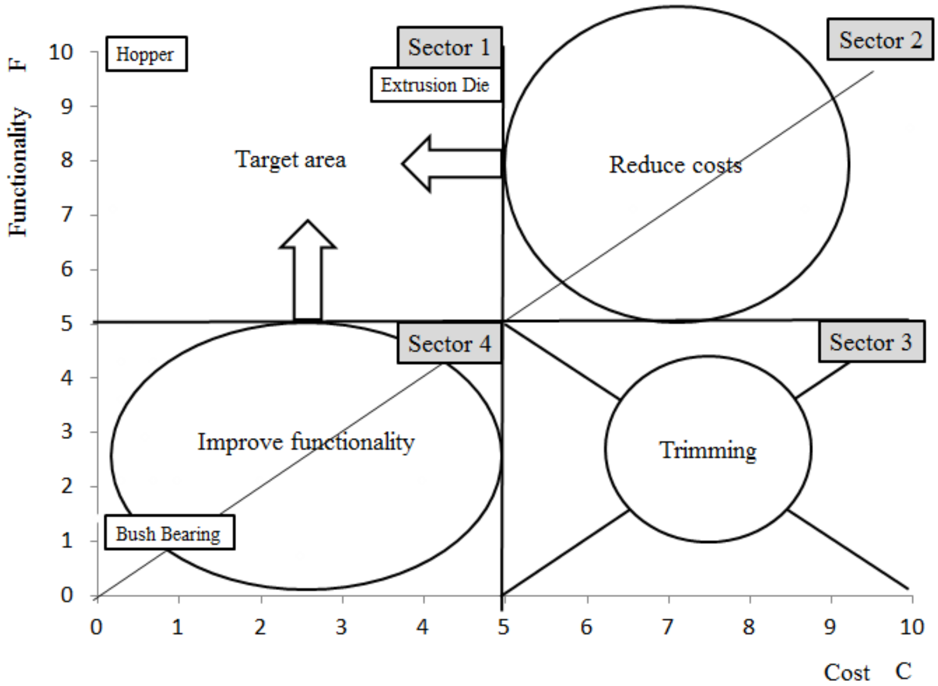


Fig 10. Strength diagram of the second generation recycling unit

4. Discussion & Conclusion

This section discusses the results of the application TRIZ function analysis in the presented project works and highlights the development with the help the TRIZ function analysis and it corresponding function models. Application advices for the TRIZ function analysis are given. Finally, aspects of the application of the geFA are presented.

The presented results of the application of TRIZ methods for the further development of a recycling unit for filament (esp. extruder) showed that the TRIZ function analysis is a powerful basic method for the analysis of technical problem statements and suitable to provide a starting point for the development of solutions. The development of the extruder function models clearly shows the evolution of an abstract solution idea (cf. Fig 1: black box model) to a detailed system depiction of specific components (TRIZ function models Fig 6 - Fig 9). The black box model represents the main in- and outputs of the system. This very abstract model generates a wide solution space on the one hand, but on the other hand visualizes important parameters, which have to be considered for the generation of solution ideas. Bottoming-up of the black box model, creativity methods like morphological chart, which gathers solution ideas for different functions, can be applied [10]. Since all of these solutions need to be structured, assessment methods, like scoring, should be applied. First solution ideas can be depicted with the flow-oriented function analysis [3]. All these development steps are barely supported by TRIZ. The real strength of TRIZ is revealed when technical systems need to be developed further or improved. Synthesizing on first idea drafts, e.g. prototype of the first-generation extruder, new ideas can be developed. The function models of TRIZ analyses the system regarding cost, functionality, and possible contradictions. All these have been shown in the results of the presented case study (cf. Section 3). The function model depicts the components of the system and their interaction (in form of functions). The transition from the black box model (abstract model) to the function model (specific) leads to a focused depiction of the system characteristics. The solution space gets narrowed down, but TRIZ tools like Incremental Improvement, Value Analysis, or Technical Contradictions can be applied. Depending on the stage of development the useful application of TRIZ function analysis has to be discussed. Even though TRIZ function analysis exhibits limitations in case of a new product development process in the point of view of the authors, it should be one of the first choice tools or developments steps of system analysis and structuring of existing systems, since it paves the way for a systematic enhancement the system.

The approach advances the TRIZ function model with a graphical representation of the system. This approach facilitates the development of the function model and improves communicability of system models. Following aspects had been observed during the application of the geFA approach:

- The cutaway model as a system depiction provides a good basis to increase the interpretability of TRIZ function models, since physical relationships of systems components lead to function relationships in function model. This coherence can be reinforced with the adapted approach.
- The arrangement of the components following the cutaway model of the system (e.g. material extruder in Section 1) was facilitated and with this the interpretability was further increased.
- Force and material flux through the system as well as their direction are displayed.
- Third parties with little or no previous knowledge, e.g. colleagues, project partners, customers, can easily understand the coherence of functions and components. This provides a good discussion platform of the system.
- TRIZ FA and geFA allow the identification of patterns, e.g. technical or physical contradictions through the interaction of useful and harmful functions.

Since the approach has been applied in limited use cases, the application and discussion of geFA in further fields and industries is of interest.

References

1. RepRap: <http://reprap.org/wiki/RepRap> - 29.04.2014

2. Barbier, L.: Entwicklung einer Aufbereitungseinheit von Kunststoffen für Open-Soruce Rapid-Prototyping-Maschinen. Diplomarbeit, Technische Universität München (2013).

3. Lindemann, U.: Methodische Entwicklung technischer Produkte: Methoden flexibel und situationsgerecht anwenden. 3rd Auflage. Springer DE 2009. ISBN: 978-3-642-01422-2.

4. Münzberg, C.; Michl, K.; Heigl, H.; Jeck, T.; Lindemann, U.: FURTHER DEVELOPMENT OF TRIZ FUNCTION ANALYSIS BASED ON APPLICATIONS IN PROJECTS. ICED 14. Croatia, Dubrovnik, May 19th-22nd, 2014 2014.

5. Adunka, R.: Innovationsmethodik - TRIZ Basiskurs Level WS13/14. 2013,

6. Altshuller, G. S.; Shulyak, L.; Rodman, S.; Fedoseev, U.: 40 principles: TRIZ keys to technical innovation. Technical Innovation Center, Inc. 1997. ISBN: 0964074036.

7. Klein, B.: TRIZ/TIPS-Methodik des erfinderischen Problemlösens. Oldenbourg Verlag 2007. ISBN: 3486580833.

8. Orloff, M. A.: Inventive thinking through TRIZ: a practical guide. Springer 2006. ISBN: 3540332235.

9. Heigl, H.: Kritische Analyse und Verbesserung eines "Recyclers" anhand der TRIZ-Methodik. Diplomarbeit, Technische Universität München (2013).

10. Zwicky, F.: Entdecken, erfinden, forschen im morphologischen Weltbild. Muenchen: Droemer,| c1966 1 (1966)

Author (co-author) to contact: Christopher Münzberg, muenzberg@pe.mw.tum.de

TRIZfest 2014

Disruptive Technologies and Disruptive Innovations

Alex Lyubomirskiy

GEN3 Partners, Boston, USA

Abstract

The paper presents one of the previously unknown internal mechanisms of disruptive innovations: achievement of positive economic results disproportionate to the invested effort via mobilization of previously underutilized natural, technological or market (social) resources.

Keywords: innovations, technologies, disruptive, planning.

1. Introduction

1.1. Background

At present innovations are one of the principal engines of economic development. In the recent past much attention was paid to revolutionary (breakthrough) innovations that provide a radical improvement of product parameters, usually by using new principles. Now, however, there is increasing interest in disruptive innovations capable of radically changing the rules of the game and the situation on the markets. The term was introduced by Clayton Christensen fairly recently, in 1995, but it generates over 30M Google results by now.

Prior art approach (1) considers disruptive innovations as those that create new markets, often by making the product significantly cheaper including via sacrificing quality. Classic example of such an innovation is the assembly line manufacturing of Ford's Model T cars (Fig. 1).

Fig. 1 Ford assembly line

This significantly reduced price via employment of inexpensive low skilled workers and considerable reduction in quality on many parameters (speed, comfort etc) compared to higher end models; thus allowing for expanded consumer base and creating an entirely new market segment.

1.2. Disadvantages of the existing approach. Goal of the paper.

Interest in disruptive innovations is understandable: by creating new market segments they are able to generate significant profits, whereas simultaneous collapse of existing segments can cause equally significant losses to competitors. Hence it is essential to have a practical and reliable tool allowing planning this kind of innovations or at least predict them somewhat reliably.

We believe that the existing approach does not fully provide this ability because it allows identifying a disruptive innovation only retrospectively when its main characteristics -- creation of new markets -- is demonstrated. The second of the currently known criteria -- significant price reduction -- also does not seem to us sufficiently reliable. E.g. introduction of the iphone radically altered the mobile devices market even though it did not involve significant price decrease (in fact, prices rose).

Thus the goal of this paper is to eliminate these weaknesses (insufficient practical utility and mostly retrospective validity) and to identify underlying mechanisms that allow innovations to become disruptive.

2. Hypothesis

To find out mechanisms of disruptive innovations we can proceed as follows: create a sufficiently representative list of past innovations of this type and try to identify common ways in which they achieved disruption i.e. changed the rules of the game and completely altered the situation in their market segments.

Table 1: Disruptive innovations

Use of fire	Sewing machine	Batteries
Agriculture	Steam engine	Antibiotics
Ceramics	Internal combustion engine	Refrigeration
Metallurgy	Electrical starter motor	Pasteurization
Glass making	Telephone	Vacuum tubes
Gun powder making	Electric lamp	Computers
Paper making	Plastics	Internet
Book printing		Iphone

This list is clearly far from complete, but it is sufficient to identify commonalities. The first thing immediately apparent here is that the majority of technologies underlying disruptive innovations are of the breakthrough type i.e. based on new mechanisms of action. But not all of them! For example, book printing, sewing machine and many other such machines and contraptions large and small including spinning machine, mechanical weaving loom, “cotton gin” device for removing seeds from fiber etc. use well known mechanisms of action; it is just a matter of adding mechanical transmission (and subsequently engine) to the slightly modified working tool (seal in printing press, sewing needle, flying shuttle, brush). Also, development of new mechanisms of action usually takes lots of time and money with no certainty in good final outcome. So we ought to look for something else.

We note another characteristic feature -- the effect from such innovations is disproportionally large compared to efforts invested. For instance, let's compare two innovations in cars: electrical starter motor and power windows. In terms of technical complexity these two innovations are not equal but nevertheless comparable. Yet, the results are very different. Power windows slightly improved comfort and safety of driving but did not yield any major change. Starter motor, by contrast, allowed widespread use of cars by women since starting a car manually used to be too physically taxing and likely to cause injury to suit an average housewife (Fig. 2).

Fig.2 Crank starter

The car, in turn, allowed them to find employment in industry providing millions of new jobs and giving working women economic independence and possibility of career advancement. Thus a relatively minor local improvement affected such apparently unrelated areas like divorce rate, birth rate and sexual morality.

There exists a type of phenomena characterized by high output amplitude given small initiating impulse -- these are so-called autowave processes that occur in environments with dispersed energy sources (2). Forest fire and snow avalanche are examples of such processes, using the chemical energy of wood and potential energy of snow on the mountain side, respectively.

If we assume that disruptive innovations (that, in the same way, provide a disproportionately large output) follow a similar pattern, we may conclude that they also **put into use some sort of previously underutilized resources**. Sure enough, any of the technologies in the above list puts into use some kind of resources: natural (e.g. metallurgy turns useless rocks into a construction material with phenomenal properties while glass making does the same with sand) or social ones (starter motor turns housewives into car buyers and employees, and social networks turn regular bloggers into public opinion leaders).

Quite likely it is also possible to have the unused (or underused) resources consist of already existing technologies. In this case disruptive innovation serves as a type of capstone or missing link that joins them into unified chain. For instance, the same starter motor apparently joined the chain “housewives - cars - jobs” where cars and jobs are technologies and housewives a social resource.

Both statements can be illustrated with the “cotton gin” – a machine that separates cotton fibers from their seeds (Fig. 3, 4):

Fig. 3 Cotton fibers with seeds

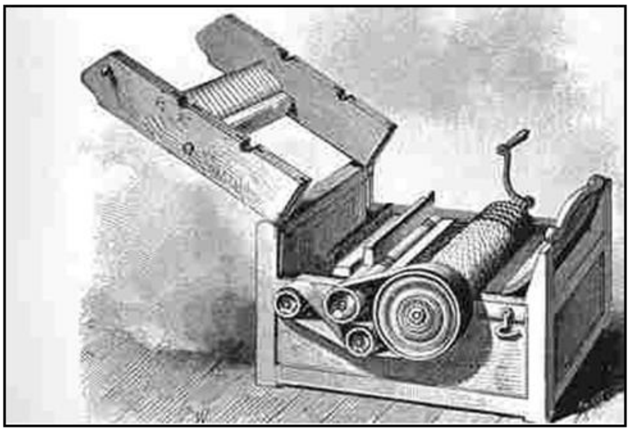


Fig. 4 Cotton gin

In the end of 18th century the major problem of the South was: how to produce enough cotton to meet the demands of England's newly invented spinning and weaving machines. A black-seed, long-staple cotton was easily cleaned, but it grew only near the coast, while a green-seed, short-staple variety grew in inland areas but resisted cleaning since its fiber stuck to the seed. Nevertheless, before cotton can be used, the fibers must be separated from the seeds. Done by hand, it takes a day to get a pound.

Never having seen raw cotton, inventor Eli Whitney within days made a crude model. Based on simple principles, the Cotton Gin was finished in 1793. By 1800 cotton production had increased from about 3,000 bales a year to 73,000. <u>His cotton-cleaning invention brought prosperity to the South.</u>

One can say that there were two effective technologies: green-seed cotton cultivation and fabric manufacturing. They could not work together due to the barrier: extremely ineffective cleaning. Cotton gin broke this barrier, and 3 underused resources: inland areas, green-seed cotton, and slaves (well, it is history…) were mobilized.

There are also innovations entirely in the realm of business that provide for access to new resources purely via organizational changes. An example of that is franchising i.e. easily scalable business model based on mobilizing the market resource of independent business proprietors (Fig. 5).

Fig. 5 Franchising

Another example is outsourcing: outsourcing companies mobilize inexpensive labor resources of other countries.

We also note that significant price reduction mentioned earlier as a necessary attribute of disruptive innovations is simply one of the ways to get access to the typical market resource - the mass consumer base.

3. Conclusions

We have identified one of the previously unknown internal mechanisms of disruptive innovations: achievement of positive economic results disproportionate to the invested effort via mobilization of previously underutilized natural, technological or market (social) resources. In some cases this requires creating a fundamentally new (breakthrough) technology, but this usually involves long and expensive development and deployment. For best results it is thus preferable to develop “missing links” i.e. relatively uncomplicated products that allow to join already existing technologies and other resources into workable chains.

This paper does not answer the question of how and where we should look for promising resources and design chains that may be “completed” with the missing link technologies. Nevertheless, an understanding of the autowave nature of disruptive innovations and their underlying mechanism is useful both for correct problem definition (i.e. if we need a disruptive innovation we should look for underutilized resources and technological chains in need of completion) and for estimating the value of planned innovations (i.e. whether they are likely to prove disruptive through access to extensive resources and/or completing technological chain).

References

1. Christensen, Clayton M. (1997), The innovator's dilemma: when new technologies cause great firms to fail, Boston, Massachusetts, USA: Harvard Business School Press, ISBN 978-0-87584-585-2.

2. Vasiliev, V.A.; Romanovskii, Yu.M.; Chernavskii, D.S.; Yakhno, V.G. (1987). Autowave Processes in Kinetic Systems. Spatial and Temporal Self-Organization in Physics, Chemistry, Biology, and Medicine. Berlin: Springer Netherlands.

Author (co-author) to contact: Alex Lyubomirskiy, Alex.Lyubomirskiy@GEN3.com

TRIZfest 2014

Electronic reference book of typical disadvantages as an integrated educational tool

Yuri Danilovsky[a], Sergey Ikovenko[b]

[a]QM&E / Gen3 Korea, Suwon, 463-825, South Korea

[b]Gen3 Partners / Massachusetts Institute of Technology, Boston, MA 02110, USA

Abstract

A new educational tool is suggested to facilitate the practical use of classical TRIZ tools by students. The instrument is based on the concept of typical disadvantages and their relation to physical contradictions in engineering systems. We consider the disadvantage as a shortened form of formulation of physical contradiction. Thus, all disadvantages are grouped into 5 categories depending on the kind of critical resource: Substance, Field, Time, Space, and Function. Totally we separate 30 typical disadvantages. For each of them, we found the most typical inventive principles, standards and trends that are frequently used for overcoming this type of disadvantages. They were found by analysing the data about 5000 known inventions that were realized in the market. The new tool is available as an electronic reference book where each typical disadvantage is linked to corresponding principles, standards and trends. For each of these links, practical examples are suggested. Experience of practical use of the suggested instrument in our educational courses has demonstrated high effectiveness: the students better realize the studied TRIZ tools (trends, principles, standards), faster find the solution, and resolve greater percent of problems.

Keywords: TRIZ, education, disadvantage, principle, trend, standard solution.

1. Introduction

All main instruments of classical TRIZ (inventive principles, standard solutions, ideal final result, trends of engineering systems evolution, ARIZ) are based on general concept of contradiction in a Technical System (TS). TRIZ operates with several kinds of contradictions; among them, the most usable are Technical Contradiction (TC) that describes undesirable consequences of improving TS (if we do something with the system then we improve A but inevitably worsen B), and Physical Contradiction (PC) that describes opposite requirements to the same parameter of TS (the value of parameter P should simultaneously be big to achieve desirable result C and small to achieve desirable result D). In this paper we present the new educational instrument that integrates Physical Contradictions with the instruments of classical TRIZ.

When performing educational courses in different countries we face the same problem: it is difficult for students to realize the concept of “contradiction” and “to think In terms of contradictions”. Such way of thinking requires much time and efforts from both students and teachers (trainers, coaches, facilitators), especially if they belong to different cultures. On the other hand, today reality of TRIZ education requires obtaining the first practical results “right now”, maximum, in the end of the first training day: otherwise, typical customers consider

TRIZ "too much complicated", "not friendly", "ineffective", etc. As a result, students have insufficient motivation to TRIZ-education, which complicates obtaining new skills and knowledge and considerably decreases the efficiency of such education in general.

The problem can be formulated as a contradiction: starting TRIZ-education should take short time to save the motivation of students to learning TRIZ, and it should take long time to realize the general concept of contradiction as a base of all instruments of classical TRIZ. Here we try to improve this situation.

2. Prior Art

The problem of long "learning curve" is not new in TRIZ. The founder of TRIZ Genrich Altshuller made much effort to make basic TRIZ education faster and more efficient. One of the first attempts in this direction caused the development of the worldwide-known Contradiction Matrix [1, 2]. The author analyzed many descriptions of the inventions and suggested the most popular inventive principles that were used to resolve technical contradictions with the same type of conflicting parameters. This instrument was then criticized many times (mostly, on the sidelines) for low practical efficiency, but up to now it remains one of the most popular TRIZ instruments available for beginners. A new version of this instrument was suggested in [3] where the list of conflicting parameters was extended for total 50 items.

Other classical tool that was developed with the same goal (to shorten the "learning curve") was a set of standard solutions [4, 5]. The idea of this instrument was to simplify the use of rather complicated instrument, ARIZ, for the most typical problems that often have similar solutions. This tool also includes a classification based on Substance-Field modeling.

Standard Solutions and Inventive Principles are internally connected with each other. In [6], their relationship is described and tabulated: for each of inventive principles, the authors specified one or more standard solutions that use this principle. Essentially, the mapping table suggested in [6] can be considered as a new classification of standard solutions.

Similar solution was suggested by Fedosov [7] to simplify teaching the concept of function: the author compiled a "handbook of elementary functions" that covered the majority of practical situation requiring functional analysis. Then, a rather complicated and error-prone procedure of formulation of particular functions was replaced for selection of proper function from the list. Similar idea was suggested in [8].

If we try to integrate the basic ideas suggested in these and many other papers, we can formulate the "mainstream" of suggested solutions as follows:

(1) Specify the category which learning is difficult ("function", "contradiction", etc.);

(2) Suggest a new classification of this category basing on its key element ("conflicting parameter" for TC, "substance-field model" for standard solutions, etc.);

(3) Suggest a simple way of attribution of a particular problem to a corresponding class of this classification;

(4) For each class of the suggested classification, specify one or more typical (popular, frequently used) instruments that effectively work with this class of problems.

In this paper, we apply the same general strategy to physical contradictions.

3. Disadvantage as a Key Term for Physical Contradiction

Logics of all known versions of inventive algorithms (ARIZ-85, ARIZ-CMBA, AVIZ, etc.) is essentially very similar. All of them start from the description and definition of some “inventive situation” in terms of some or other inconvenience in the prototype, unsatisfactory complexity of performing the function, too high cost, etc. All of these issues characterize disadvantage (DA) of the existing system as the first, basic category to be analyzed. Then we convert the description into the “language” of parameters and build a TC for understanding of the causal link of this DA. Afterwards, we built a model of PC as a new heuristic single-parameter model where the DA is considered in the form “a parameter P should be big (for something) and small (for something else)”. Then we build the next heuristic model of the DA on the base of concept of Ideal Final Result (IFR), with two key phrases: (1) my new system contains some “X-element” that causes disappearing the DA, and (2) the new system prevents the DA ***itself***, without special intervention. The solution of this “equation system” (finding a common solution for all of these models) helps a solver to focus his/her thinking to search for a solution as some image, “portrait” of possible solution.

In this paper, we use the term “disadvantage” as a synonym of “undesirable effect”. With the term “disadvantage” we underline the practical focus of TRIZ instruments: to get a competitive advantage, to make a new or improved system better than its previous variant; in other words, to suggest something that satisfies objective requirements to a system, not somebody’s desires.

As follows from the above reasoning, the DA is a key category in the process of the development of a new TS, as far as the concept of DA is used in some or other way in all instruments of classical TRIZ: in TC, PC, IFR, standard solutions.

Basing on this general understanding, we suggest a rather simple classification of the most “popular” typical DA that force a solver to find a new inventive solution of a problem.

We have to notify that G. Altshuller tried to do something very similar in the Appendix 1 to ARIZ-85C [9, 10] where he described 11 typical models of conflicts. Unfortunately, our experience shows that practical use of this classification in TRIZ education is rather difficult: the students very often confuse different kinds of conflicts, improperly determine their “sides”, and, as a result, just “draw a picture” instead of understanding the nature of the conflict.

We see the probable reason of this difficulty in inconvenient language of description that is based on the term “conflict”. Much more convenient and habitual language uses no “conflict” but “parameter”.

For example, it is very easy to describe the disadvantage of a pencil in the form: “long use of a pencil causes pain in fingers of an arm that holds it”. After some analysis, we could formulate a TC that connects the time of use with some characteristics of the pencil itself, i.e. its ***hardness***, and then move to a PC where this second parameter (hardness) would be used: “hardness of pencil should be big to save the shape of pencil and small to avoid causing the pain in fingers”.

Certainly, operating with the parameter “hardness” simplifies the search for a proper solution. However, to come to this “secondary” parameter we need considerable time and effort. At the same time, if we come back to the source formulation we can see that it already contains some parameter: ***time of use***. In fact, we can rewrite this formulation in the form of PC: “time of use should be big (to write the required text or draw picture) and small (to prevent the pain in fingers)”.

The experienced TRIZ specialists often call such PC-like formulas derived from the source problem formulation as “proto-PC” or “initial PC”. The general recommendation is ***not to try to resolve*** this “proto-PC”, as far as the information about the problem is often insufficient, and continue the analysis to formulate the “proper PC” (in our case, concerning the hardness of pencil). The same recommendation can be derived from the text of ARIZ [9] where the initial formulation should be transformed to a TC and only afterwards to a PC. Reasoning about “erroneous” intension to resolve PC without formulating TC can be found, for example, in [11] where the author underlines limited application of such simplified approaches. We completely agree with the last statement and consider only the situation of basic TRIZ education within very limited time (1-2 working days for the course), as far as such time limit was specified by very many our customers.

Analysis of about 5000 inventions realized in the commercially successful products showed some essential relationships between the kinds of parameter mentioned in a “proto-PC” and particular TRIZ instruments (principles, trends, standard solutions) that typically allow resolving the problem. For example, the problem of ***expendable substances*** (that can be rewritten in a “parametric language” as “too high ***consumption of substance***”) is very often solved by using the trend “***transfer to Supersystem***”: pen transforms to computer (eliminating the ink), oven transforms to electric cooker (eliminating the fuel), etc. In other words, problems with similar disadvantages often have similar solutions.

Note that similar idea is indirectly used in the Functional Oriented Search (see e.g. [12]): if a problem is properly formulated in the “language of parameters” then (after translation to the “language of functions”) it is possible to find a solution in some far enough domain area and use its operation principle to improve the source system. In other words, there is a rather high probability to find similar (working!) solutions for systems with similar disadvantages initially formulated in terms of the same parameters.

In the present paper, we suggest a new instrument that integrates significant parts of our knowledge about DA and their connection with the instruments of classical TRIZ.

4. Mapping of Disadvantages to Classical TRIZ Tools

As it was stated above, to practically use the idea of “similarity by disadvantage”, especially in basic TRIZ education, we need some simple and convenient classification; in our case – the classification of disadvantages.

Earlier [13], we suggested a new classification of disadvantages basing on the use of five general categories that are widely used in TRIZ: ***time, space, field (energy), substance, and function***. This classification contained 36 typical DA. However, our experience in TRIZ consulting and education shows that six of them have never appeared in our projects (we tried to apply this approach backdating to several hundred previous projects). Thus, we excluded these six types of DA from our classification to reduce the “information noise”.

The suggested classification is presented in Appendix 1. This classification was derived empirically and, therefore, does not pretend to be complete. However, it covers an overwhelming majority of real-world problems that we resolved last time.

In Appendix 2 we summarize the results of our analysis of 5000 inventions realized in commercially successful products. The table describes the instruments that get the tips how to come to these solutions from previous state of the system.

Like other tools of this kind, the suggested mapping does not pretend to be complete but suggests the recommended tools. The names and descriptions of inventive principles and standard solutions are omitted to save space.

5. Practical Application

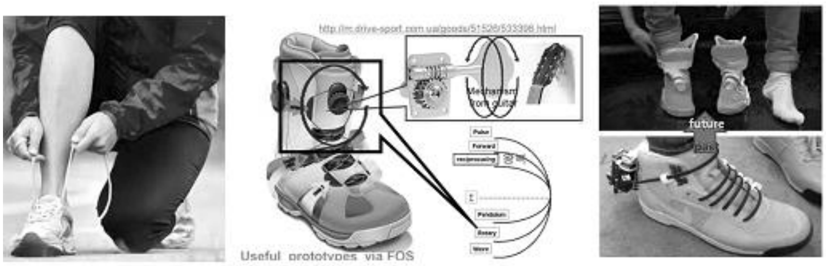
The suggested map of disadvantage overcoming tools was used in numerous educational courses and showed positive results. Our students were able to attribute particular problems to one or few of 30 typical DA after about just an hour of study. The use of the suggested principles and trends was available to beginners, right after learning corresponding tools. Standard solutions appeared not as easy in use, but in the basic (1-2 days) educational courses we did not even try to use them, as far as this instrument requires high enough qualification of a solver. Let us present only one practical example of students' work.

The task was formulated as "to suggest idea of shoes easy to put on and off". The students attributed the disadvantage of the prototype system to the type 10 "High energy consumption when preparing to use". By using the instruments recommended for this type of DA they suggested several ideas, two of them are presented in Fig. 1.

We have to note that, although this instrument was planned to use only in educational projects, in fact we also used it in our own projects as an auxiliary instrument.

In Fig. 2, one example is presented. The problem was to suggest a new concept for the clamp for air tube. Key disadvantage was determined as "High energy consumption when preparing to use" (# 10). Our preliminary analysis according to Appendix 2 allowed us to suggest several ideas that were suggested to the customer in our final report.

Thus, we think that the suggested approach may be useful not only in educational projects for beginners but also for professionals in the stage of preliminary search for simplest solutions.



a b c

Fig. 1. Ideas for problem of shoes easy to put on and off: a: essence of the problem; b: idea according to standard solution 5.2.1; c: idea according to the trend of completeness

a b c

Fig. 2. Ideas for clamp for air tube: a: essence of the problem; b: idea according to trend of dynamization, c: idea according to principle # 17 (go to other dimension)

6. Conclusions

The need to accelerate educational courses forced us to find new approaches to old problems of TRIZ education, one of them being the necessity to quickly teach the student to operate with the basic concept of contradiction in general and physical contradiction in particular. Our previous experience showed that the students, especially belonging to different (e.g. Asian) cultures, faced serious difficulties in understanding what these "contradictions" mean. This difficulty caused some frustration that appeared as perception of TRIZ as something "difficult" and "inconvenient", "not user-friendly", etc.

The suggested instrument was developed to facilitate the basic TRIZ education, make it easier and faster and, therefore, save motivation of students to learn TRIZ. We found long time ago that, although the students have serious problems with formulation of contradictions, they usually have no difficulties with formulation of disadvantages of the system to improve. Thinking in terms of competitive disadvantages as undesirable values of some parameters of a system was natural for most of them and did not require special learning. When developing the instrument, we tried to use this basic ability of our students to facilitate TRIZ education.

The instrument is based on general assumptions that was made long time ago, namely – the assumption that similar problems often have similar solutions. As a criterion of "similarity", we used the type of disadvantage specified in the original description of inventive situation. For that, we suggested a new classification of disadvantages. Our classification groups known disadvantages into 30 types in 5 general categories widely used in TRIZ: time, space, substance, field, and function. For each of these 30 types, we found the most applicable tools that provide a solver with working tips. For that, we analyzed about 5000 inventions that were realized in commercially successful products. Finally, we obtained a "map" that links typical disadvantages to classical TRIZ tool. This "map" was compiled in the form of electronic reference book.

During the last period, we tried to apply the suggested method in our educational courses and got positive results. Our students got the basic practical skills faster, found more ideas of solutions, better realized the sense of the learned TRIZ tools.

As a "side effect", the suggested method became effective in our own projects as well: it allowed saving some time when searching for the simplest solutions. An example of such solution is described above.

We believe that the suggested approach facilitates learning the classical TRIZ tools (trends, principles, standard solutions) and allows better understanding of basic concepts of TRIZ.

References

1. G.S.Altshuller. The algorithm of invention: Moscow, Moskovsky Rabochy, 1973, Appendix 1 (in Russian).

2. G. Altshuller, The Innovation Algorithm, TRIZ, systematic innovation and technical creativity, Worcester, MA: Technical Innovation Center, 1999.

3. D. L. Mann, "Comparing the Classical and New Contradiction Matrix Part 2- Zooming In", The Triz Journal, 2004.

4. G. Altshuller. Standards for solving inventive tasks, 1975, http://www.altshuller.ru/triz/standards1.asp (in Russian)

5. I. Bukhman. System of standard solutions, http://www.triz.com.tw/isak2/Ideas_standard%20solution.html

6. E. Domb, J. Terninko, J. Miller, E. MacGran. The Seventy-Six Standard Solutions: How They Relate to the 40 Principles of Inventive Problem Solving. TRIZ Journal, 1999, http://www.triz-journal.com/archives/1999/05/e/

7. Yu. Fedosov. Statistics of "elementary functions". TRIZ Summit, 2009.

8. Kynin A., Priven A. Formulation of functions of an engineering systems with the matrix of generalized parameters // Proc. Int. Conf. “TRIZfest-2013”, Kyiv, Ukraine, August 1-3, 2013. – MATRIZ, St. Petersburg Polytechnic University publishing house, 2013, p. 59-67.

9. G. Altshuller. Algorithm of Solving the Inventive Problems ARIZ-85C, 1985, http://www.altshuller.ru/triz/ariz85v.asp

10. J. Marconi. ARIZ : The Algorithm for Inventive Problem Solving. TRIZ Journal, 1998, http://www.triz-journal.com/archives/1998/04/d/

11. B. Goldovsky. Statements in favor of contradictions in technical systems, part 3, 2014 (in Russian), http://www.metodolog.ru/node/1827

12. S. Litvin. New TRIZ-based tool — function-oriented search (FOS), TRIZ Journal, 2005, www.triz-journal.com/archives/2005/08/04.pdf

13. Yu. Danilovsky. Projects of 2010-2011. Proc. 3rd Conf. “TRIZ. Practice of use of methodic instruments”, 2011 (in Russian), http://www.metodolog.ru/node/1213

Appendix

Table 1: List of 30 typical disadvantages

##	Description
Substance	
1	Undesirable substance
2	Disposable substance
3	Low productivity of using substance
4	Low usable energy of substance
5	Need to remove substance
6	Insufficient control of substance flow
Field	
7	Undesirable field
8	High weight
9	High energy consumption when using
10	High energy consumption when preparing to use
11	High energy consumption when switching
12	Many moving parts
Space	
13	Big size when transportation
14	Big size when storing
15	Improper shape
16	Trivial shape (and color)
17	Small distance of useful action
18	No mobility
Time	
19	Short life time
20	Long time of charging
21	Small resource of autonomous work
22	Long preparation to use
23	Long operating time

24	Long learning curve
Function	
25	Needs correction function
26	Excessive level of function
27	Insufficient level of function
28	Insufficient additional functions
29	Insufficient reliability
30	Requires additional system

Table 2: TRIZ tools recommended for overcoming the disadvantages specified in Table 1

DA ##	Trends	Standard solutions [4]	Inventive principles [1]
1	Ideality MATCEM Harmonization	2.2.5,3.1.5,5.1.1.1,5.1.3	2, 9, 10, 11, 22, 23, 24, 31, 34, 38, 39
2	Supersystem Macro-micro Ideality	3.2.1, 5.1.1.1,5.1.3	13, 28, 35, 36, 25
3	MATCEM Conductivity Ideality	1.1.1, 1.1.4,1.1.5, 2.2.2,2.2.4, 3.2.1,5.2.1, 5.2.2	9, 14, 18, 34, 38
4	MATCEM Macro-micro Ideality	1.1.2, 1.1.5,2.3.1, 5.3.1	35, 36, 38, 39
5	Harmonization Supersystem Macro-micro	1.1.6, 3.1.3,3.2.1, 5.1.3	1, 5, 6, 9, 10, 14, 16, 25
6	Completeness Harmonization Dynamization	1.1.3, 2.3.3,5.2.3	1, 2, 3, 7, 15,13, 19, 20, 24, 25,31
7	MATCEM Macro-micro Harmonization	1.1.5,1.1.6,.1.1.7,1.1.8, 1.2.2.1.2.3,1.2.4,1.2.5,3.1.3, 4.5.1, 4.5.2,5.1.1.1, 5.2.1,5.3.3, 5.3.4	1, 2, 3, 7, 11, 17, 24, 35, 40
8	Dynamization Supersystem Harmonization	1.2.2, 1.2.4, 5.1.1.1, 5.1.4	8, 15, 28, 29, 30
9	Supersystem Macro - micro Ideality	2.2.2, 3.1.1,3.2.1, 5.2.1,5.3.2, 5.3.5	35,36,12,28, 1
10	Completeness Conductivity Dynamization	2.4.1, 3.1.5, 5.1.1.1, 5.2.1,5.4.1	9,23,15,17
11	Ideality Conductivity Supersystem	3.1.5, 5.2.1,5.4.1	12,15,17,10,25,23
12	Macro – micro MATCEM Conductivity	1.2.2, 1.2.4,3.1.5, 3.2.1,4.1.2	9,10, 28,30, 35, 36, 26,13

13	Dynamization Ideality MATCEM	2.2.4, 3.1.2,3.1.5, 5.1.4	7,15,17,28,29,30,35
14	Dynamization Harmonization Supersystem	2.2.4, 3.1.5,5.3.1	7,18,17
15	Harmonization Dynamization Ideality	2.2.4, 3.1.2,5.1.4	2,3,4,7, 15, 19, 23, 23, 28.
16	Ideality Supersystem Harmonization	2.2.4, 3.2.1	32,26
17	Completeness MATCEM Supersystem	3.1.1, 3.1.4,5.2.2	19,20,22,8,23,28,35
18	Supersystem Dynamization Ideality	5.1.4, 5.4.1	2, 17,15,13
19	Harmonization Ideality Dynamization	1.2.3, 1.2.4,3.2.1, 5.1.1.1	9, 10, 3, 29, 30,39,40,34
20	Harmonization Ideality Dynamization	2.2.4,5.3.5, 5.1.1.1	1,10,12,7,18,23,34
21	MATCEM Macro - micro Ideality	3.2.1, 5.3.5,5.4.1, 5.5.1	28,35,36,19,20,12
22	Supersystem Macro - micro Ideality	1.2.2, 1.2.4,2.2.4, 2.2.6,3.1.2, 5.1.1.1	10, 1,2,7,23,25
23	Completeness Dynamization Supersystem	1.1.1, 1.1.5,1.1.8, 2.2.4	14,18,21,7,15,17, 2,9,10
24	Supersystem Completeness Dynamization	2.2.4, 2.3.1	25,13,20,17,2
25	Ideality Supersystem Dynamization	2.3.1, 2.3.2, 2.1.2,2.2.3, 3.1.3,4.3.2, 4.3.5,4.4.2, 4.5.2	6,25,20,24,23,2,28
26	Harmonization Ideality Completeness	1.1.3, 1.1.5,1.2.4, 5.1.1.1	19,25,23
27	Conductivity Completeness Dynamization	1.1.1, 1.1.3,2.1.2, 2.2.2, 2.4.11, 4.2.2,4.4.1, 5.1.2,5.4.2	12,20,14,18,21,28,22,23,15,13
28	Ideality Completeness Supersystem	2.2.1, 3.1.1,3.1.3, 4.2.1,4.3.1, 4.4.1,5.3.1	6,20,32,25
29	Completeness Dynamization Ideality	1.2.1, 1.2.2,1.2.3, 2.2.3,2.4.3, 2.4.8,3.1.1, 4.4.1,5.1.1.1, 5.4.1	5,2,12,19,20,23,24,25,33,38,39,11

30	Ideality Harmonization Dynamization	1.1.3, 2.1.1,2.2.3, 3.1.1,3.1.4, 4.1.2,4.2.1, 4.2.2,4.2.3, 5.1.1.1,5.2.3, 5.4.1,5.5.1	25,20,28,12

Author (co-author) to contact: Yuri Danilovsky, yurydanilovsky@gmail.com

TRIZfest 2014

Experimental Proof of the Creative Value of TRIZ

Johannes Hass[1], Christian Rensch[1], Ruben Salvamoser[1], Christopher Münzberg[2], Udo Lindemann[2], Oliver Mayer[1]

[1]*GE Global Research, Freisinger Landstraße 50, 85748 Garching, Germany*
Tel: +49-89-5528-3412, oliver.mayer@research.ge.com

[2]*Technische Universität München, Lehrstuhl für Produktentwicklung,*
Boltzmannstraße 15, 85748 Garching, Germany
Tel: +49-89-289-15124, christopher.muenzberg@pe.mw.tum.de

Key words: TRIZ, Brainstorming, Creative Value, Innovation Speed, Experimental Test

Abstract

This paper presents a simple approach to measure the innovative capabilities of TRIZ (**T**eoriya **R**esheniya **I**zobretatelskikh **Z**adatch) and its resulting value to a company in terms of invested man-hours and the corresponding idea output. Furthermore the question whether trained TRIZ specialists can serve as multipliers and positively affect the efficiency of untrained team members is subject of this investigation.

This study is based on one technical challenge that is treated in three different idea creation scenarios that are performed by two different groups. Two of the scenarios use classical brainstorming, serving as a benchmark, and one utilizes the inventive principles of contradiction solving according to TRIZ. In comparison to both classical brainstorming scenarios, the TRIZ idea creation proved to be superior in terms of the number of ideas created per man-hour. All participants, except the moderator, had no training or knowledge of TRIZ prior to the experiment. By this experimental design it could be demonstrated that a single TRIZ trained individual can have a positive (multiplier) input on an untrained group.

1. Problem Statement

To ensure economic success, new products have to be developed at an increasing pace, under high cost and quality pressure (Lindemann 2009, p. 14). One measure General Electric (GE) applies to meet those needs is Six Sigma. Since its introduction by Jack Welch in 1996, GE is utilizing Six Sigma including the application of Six Sigma DMAIC (**D**efine - **M**easure - **A**nalyse - **I**mprove - **C**ontrol) and **D**esign **f**or **S**ix **S**igma (DFSS) very successfully for driving inventions, developments and innovations. In DFSS the 4th step "Analyze" is employed for the development of conceptual designs. During this step 4, a team of experts is formed and ideas are generated by typically utilizing brainstorming methods. Subsequently, these ideas are evaluated with regard to "engineering aspects" such as those listed in Tab. 1.

There is a subjective observation that brainstorming sessions are often influenced by a few dominant individuals in the group that can be characterized by e.g. a high level of technical expertise and experience or a superior organizational rank. These dominant individuals often promote their ideas very fast and subsequently shape the direction of the creative process for the whole group, thus limiting the creation of new ideas and concepts. As a result, creativity is channeled into a narrow flow, leading to an inferior group efficiency (Bond, Van Leeuwen 1991; Mullen et al. 1991). While the influence of dominant characters can be limited up to a certain degree by means of strict rules and an experienced moderator, the fundamental theme of triggering new ideas with previous ones, as it is the goal of brainstorming (Withing 1958), remains critical. It inevitably leads to psychological inertia as described by Altschuller (1986). This makes fundamentally new ideas rare. Alternative methods such as brain-writing show advantages in some applications, however, many of them are merely improving the idea creation process in terms of group dynamics (Harmeier 2009). Only a few methods, such as synectics, analogy or working with design catalogues give new impulses for ideas from outside (Harmeier 2009). Different from TRIZ, those methods again do not identify possible solutions in a very systematic way, usually requiring a tradeoff (Schüler-Hainsch 2006).

Table 1: Engineering aspects for idea evaluation

Engineering Aspect	Description
Performability	Will the product perform as the customer expects it to perform?
Affordability	Will the product meet cost expectations?
Featurability	Will the product provide added benefits?
Deliverability	Will the product be ready when the customer wants it?
Usability	Can the customer quickly and easily install and use the product?
Maintainability	How easy will it be to keep the product in service?
Durability	Is the product robust enough to withstand abuse?
Imageability	Will the product convey an image of quality and prestige?
Profitability	Will the product deliver acceptable levels of profit?
Investability	Does the product make sense in terms of payback?
Riskability	Are the risks that have to be taken prudent?
Produceability	Can the factory and supply chain deliver the product?
Marketability	Do we have the means to sell the product?
Growability	Does the product offer growth and market expansion for the company?
Leverageability	Does the product build on our core competencies?
Respectability	Will the product strengthen the reputation of the company?

To further improve efficiency in the idea creation process GE has started to introduce TRIZ (Teoriya Resheniya Izobretatelskikh Zadatch) starting in 2007. Since then, more than 1000 employees have been trained in TRIZ at different expertise levels and are applying the TRIZ tool box and the TRIZ philosophy to their project work. TRIZ has subjectively supported the innovative processes at GE and contributed to a variety of GE patent applications. Despite those positive results, the question about a metric for TRIZ that could be utilized to e.g. benchmark TRIZ training and implementation investments versus other innovation methods such as brainstorming has remained. Another fundamental question in this context is whether a few trained TRIZ specialists can serve as multipliers and positively affect the efficiency of untrained team members. This has big influence on the number of employees that need to be trained in TRIZ and can help to find the optimum regarding return on investment.

2. Experimental Setup

The experimental setup was designed to measure the value of the TRIZ method. The group task was to improve the actuation system for the opening and closing of a membrane valve. The actuation system consists of a shaft which is pressed against the membrane valve by a spring in its initial position (Fig. 1). In this state the valve is closed. Out of this position, it can be opened by a solenoid actuator that overcomes the spring force and moves the shaft away from the membrane valve. This actuation mechanism showed several shortcomings in routine use in terms of size, reliability, integration density and manufacturability. The goal of the group was to re-design the valve actuation mechanism.

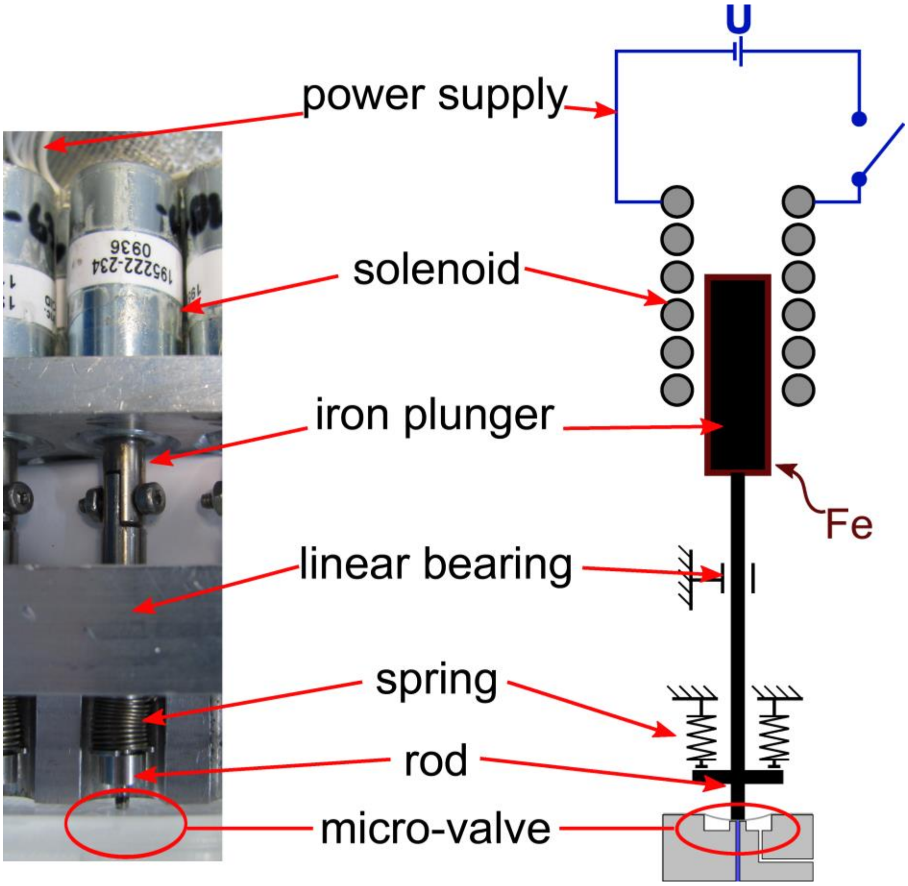


Fig. 1: Picture and schematic of the challenge (actuator opening and closing a valve)

In the first step of the experiment, a group of GE engineers and researchers with expertise in the relevant technical domain collected ideas to improve the system across a time period of 6 months (Fig. 2). During that time, ideas were generated and collected by means of conventional brainstorming.

In parallel, a TRIZ expert applied the TRIZ method to the challenge. Out of this exercise the problem statement was broken down to several contradictions. Subsequently, one major technical and one physical contradiction were selected. For each contradiction four inventive principles were chosen. In case of the technical contradiction this selection was based on the classical TRIZ contradictions table. For the physical contradiction the two separation principles “Separate in Time” and “Separate in Space” were selected due to their comprehensibility for individuals without prior TRIZ knowledge. Based on the recommendations of Mann (2009) and Gadd (2011), two inventive principles were chosen in order to receive a more specific task for solving the physical contradiction.

In a separate session, a group of 11 business experts with experience in the relevant field was invited. These individuals had not been in touch with the technical challenge nor did they know about TRIZ prior to the experiment. The business expert group included the following ranks (sorted by hierarchy): General Manager, Global Product Manager, Product Manager, Engineering Manager, Chief Engineer, Principal Engineer, Lab Manager, Sales Specialist, Lead Engineer, Research Engineer. The experiment was moderated by a TRIZ expert.

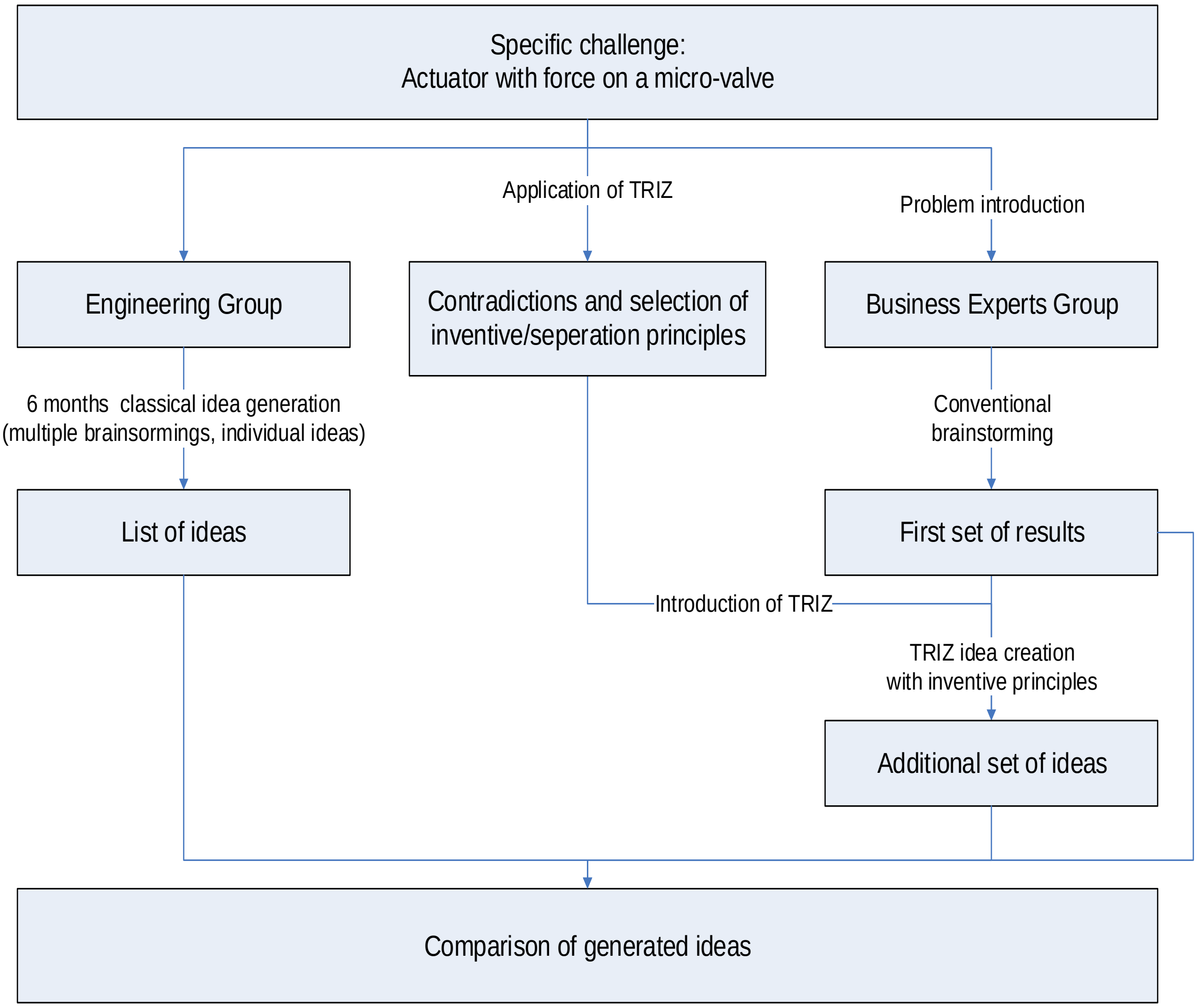


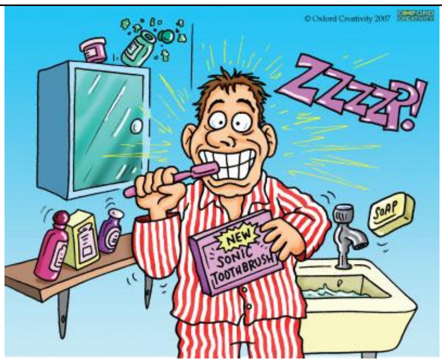
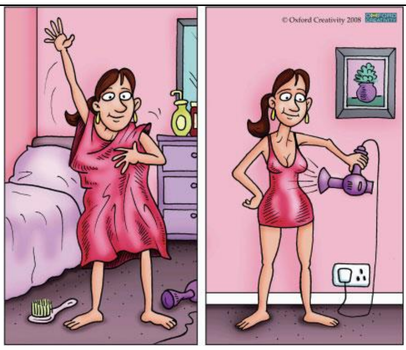
Fig. 2: Flow down of the experimental set up

The technical challenge was explained to the business expert group and a conventional brainstorming was performed in 3 groups (green, yellow, blue) of 3-4 participants each. Both, the problem introduction, as well as the brainstorming session took about 20 minutes each. During this time, the moderator was available for questions, but did not take part in the process by any other means. The ideas generated were collected on colored cards (green, yellow, blue). After the session, the ideas were collected and sorted according to technical idea categories defined by the moderator. After this exercise, the complete group was asked to identify further ideas based on what had been collected during the brainstorming. The result was displayed on a whiteboard (Fig. 3).

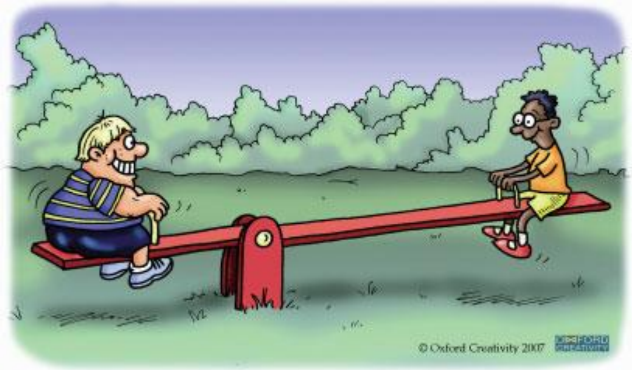
After this initial conventional idea collection, TRIZ principles selected during the preparation work as explained earlier (Fig. 2) were introduced to the business expert group without an explanation on how these TRIZ principles were created. The name of each TRIZ principle

including one explanatory picture were shown one after the other.
During this exercise, additional TRIZ triggered ideas were collected from the group. This process took 20 minutes in total. All new ideas resulting from those TRIZ generated „triggers“ were captured on red cards. The engineering team involved in the initial TRIZ analysis did neither participate in the business expert group brainstorming nor in the subsequent TRIZ principles-based idea generation process. The selected TRIZ contradictions and the corresponding 8 inventive principles listed in Tab. 2 and Tab. 3 were displayed to the group.

Table 2: Discussed technical contradiction and used inventive principles. All pictures taken from: (Gadd 2011)

<table>
<tr><td colspan="2">Technical Contradiction: “If a stronger solenoid actuator is used to open the valve, the system reliability will be increased, but then the integration density of the system decreases, as well.”</td></tr>
<tr><td>Taking Out</td><td>
</td></tr>
<tr><td>Mechanical Vibration</td><td>
</td></tr>
<tr><td>Thermal Expansion
(or Contraction)</td><td></td></tr>
<tr><td>Phase Transitions</td><td></td></tr>
</table>

Tab. 3: Discussed physical contradiction and used separation principles with the selected inventive principles. All pictures taken from: (Gadd 2011)

<table>
<tr><td colspan="2">Physical Contradiction: “A large force pointing towards the valve is desired to ensure a leakage free valve closure and the same force is desired to be small or nonexistent to ease the valve opening.”</td></tr>
<tr><td>Separate in Time - Segmentation</td><td>
</td></tr>
<tr><td>Separate in Time - Prior Action</td><td></td></tr>
<tr><td>Separate in Space - Asymmetry</td><td>
</td></tr>
<tr><td>Separate in Space - The Other Way Around</td><td>
</td></tr>
</table>

3. Results

The initial engineering group developed a total number of 11 solutions, mostly leading to minor improvements and changes in the existing actuator design, hence, presenting slight variations of the existing system. This may indicate a biased idea creation process, which is supported by the fact that the engineering team is familiar to the system and was involved in the previous design process that lead to the actuator solution under debate. The total time that was spent by the engineering group to generate the ideas is summed up to about 120 man-hours over a time period of 6 months.

The business expert group generated 14 ideas in three areas during the initial conventional brainstorming process (Fig. 3):

- Variation of actuator
- Change of system parameters and geometry
- Introduction of new system principles and/or additional components

For the problem introduction and the following brainstorming the 11 business experts and the moderator spent 40 minutes, which is equal to 8 man-hours. Together with about 1 hour of preparatory work, performed by the moderator, a total of 9 man-hours were spent for the business expert group brainstorming. Even though not emotionally bound to the existing actuator system, there were clear similarities between the ideas of the engineering group and the business expert group. As a result, 8 out of the 11 ideas created by the engineering group were rated as the same. Only 2 of the 14 ideas created by the business expert group were assigned to the category “Introduction of new system principles and/or additional components”. This shows that it is hard to separate the new idea creation process from an existing system or idea. We naturally tend to pick the low hanging fruits and create our ideas around the ones already existing.

Besides a potential influence on the quality of new ideas created, this limitation can also have an influence on the number of new ideas. Both groups, the engineering group and the business expert group, independently experienced a declining number of new ideas in the course of the idea creation process. Additionally, during a follow up discussion it was noticed that the idea creation process during the conventional brainstorming of a business expert sub-group (yellow) that contained the individual with the highest rank (General Manager) was heavily influenced by that particular individual.

Fig. 3: Result of business expert idea creation process. Ideas created with classical brainstorming are displayed on green, yellow and blue card. Red cards are showing the supplementary TRIZ “triggered” ideas.

With the introduction of the TRIZ contradictions and the TRIZ principles, additional 24 ideas were generated (red cards on the board, Fig. 3). Hence, the idea saturation point experienced by the business expert group after conventional brainstorming was overcome with the use of TRIZ. It is remarkable, that in contrast to the conventional brainstorming, 15 out of these 24 TRIZ triggered ideas were assigned to the category “Introduction of new system principles and/or additional components”. During the TRIZ triggered idea creation process, the presence of the General Manager showed a decreased impact on the group dynamics expressed by the fact that no new ideas were influenced nor built on top of an idea from this individual. The 20 minutes needed by the 11 participants and the moderator are equal to 4 man-hours. Including a preparation time of 20 hours for the moderator, the additional time spent for the TRIZ enhanced idea creation process with the business expert group sums up to 24 hours.

Besides the difference in the number and the category of ideas, there is a significant difference in time (Fig. 4): The research group required 120 man-hours in a time frame of 6 months based on conventional brainstorming creating 11 Ideas. In contrast, the prepared conventional brainstorming of the business expert group that was performed without any interruptions created 14 ideas in 9 man-hours. Subsequently, the TRIZ supported idea creation process produced 24 additional ideas consuming 24 man-hours. Together the whole business expert workshop required only 1 hour. The whole business expert group experiment including preparation work took place in a time frame of only ½ week and created 38 ideas in 33 man-hours.

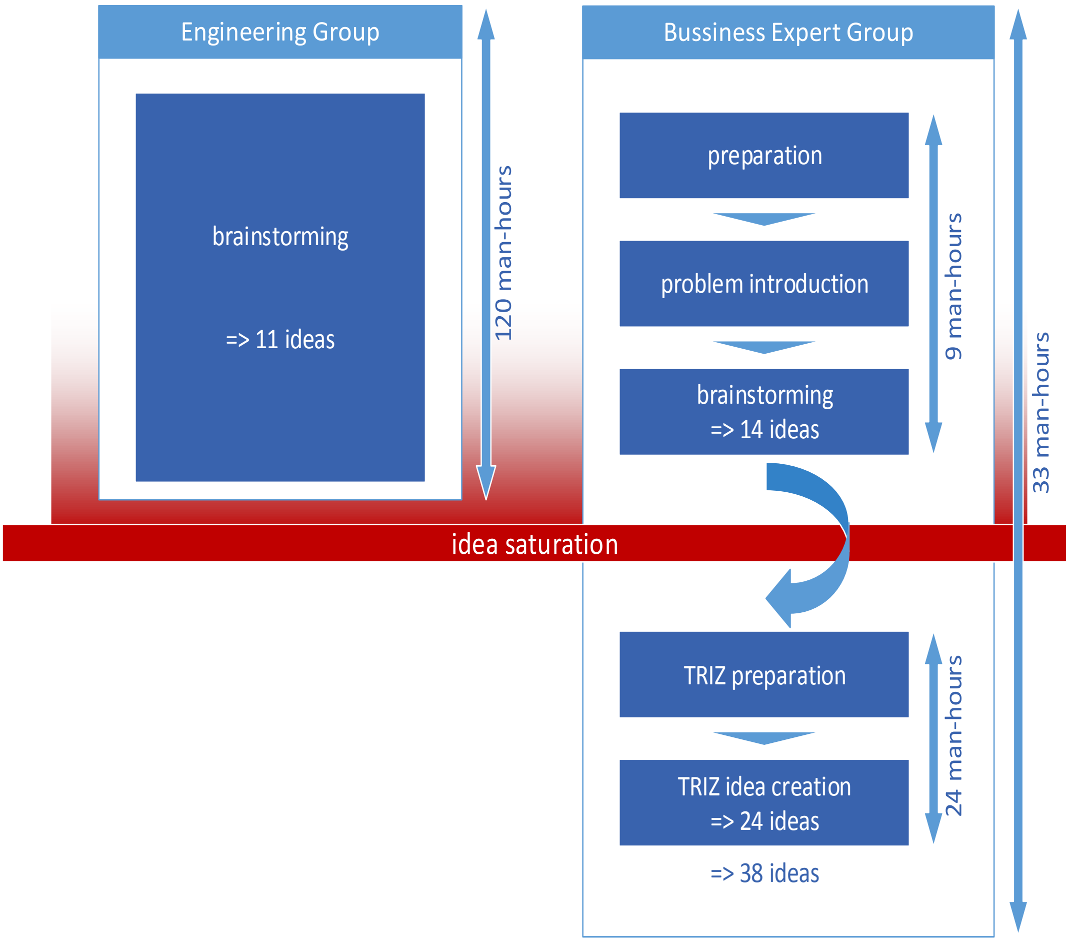


Fig. 4: Overview of the required effort and the resulting number of ideas for the different idea creation processes

4. Conclusion

This study focused on the idea creation process only. For the further problem solving process, the ideas need to be validated in a subsequent exercise, which is out of scope for the experiment described.

We found that TRIZ could clearly help to enlarge the solution space for the given problem statement. Both, the number of solutions itself, as well as the number of fundamentally new solutions, was increased by the application of TRIZ from a total of 11 ideas to 38 ideas. The idea saturation point was successfully overcome by the introduction of TRIZ principles to the business expert group. Furthermore, the process of idea creation could be accelerated. The time required for new idea creation was reduced from 6 months (=26 weeks) required by the initial engineering group to ½ week for the business expert group experiment including the TRIZ preparation by a trained TRIZ expert. The impact of group individuals with a superior rank was perceived high in the conventional brainstorming sessions of the business expert sub-groups, but low in the TRIZ triggered idea creation process. Additionally, it was demonstrated that TRIZ can be successfully used by a group without TRIZ experience nor training of every single group member. The TRIZ expert and moderator of the business expert group experiment was successfully employed to multiply his TRIZ knowledge and increase the quality and quantity of the business expert group idea creation process.

References

1. Altschuller, Genrich Saulowitsch (1986): Erfinden: Wege zur Lösung technischer Probleme. 2nd ed.: Technik Verlag.
2. Bond, Charles F.; Van Leeuwen, Marilyn D. (1991): Can a part be greater than the whole? On the relationship between primary and meta-analytic evidence. In *Basic and Applied Social Psychology* 12 (1), pp. 33–40.
3. Gadd, Karen (2011): TRIZ for engineers. Enabling inventive problem solving. Chichester, West Sussex, U.K, Hoboken, N.J: Wiley.
4. Harmeier, Jens (2009): Originelle Kreativitätstechniken. Kissing: WEKA-Media (… auf den Punkt gebracht, [2009, Oktober, Beil.]).
5. Lindemann, Udo (2009): Methodische Entwicklung technischer Produkte. Methoden flexibel und situationsgerecht anwenden. 3., korrigierte Aufl. Berlin, Heidelberg: Springer (VDI-Buch).
6. Mann, Darrell L. (2009): Matrix 2010. Re-updating the TRIZ contradiction matrix. 1. ed. Clevedon: IFR Press.
7. Mullen, Brian; Johnson, Craig; Salas, Eduardo (1991): Productivity Loss in Brainstorming Groups: A Meta-Analytic Integration. In *Basic and Applied Social Psychology* 12 (1), pp. 3–23.
8. Schüler-Hainsch, Eckhard (2006): Technologische Innovation als zu gestaltender Prozess im Sinne der systematischen Generierung von Ideen. In Günter Spur (Ed.): Wachstum durch technologische Innovationen. Beiträge aus Wissenschaft und Wirtschaft. Stuttgart: Fraunhofer-IRB-Verl. (Acatech diskutiert), pp. 29–39.
9. Withing, Ch (1958): Creative thinking. New York: Reinhold.

Author (co-author) to contact: Oliver Mayer, mayer@ibom.de

TRIZfest 2014

Financial Justification of a TRIZ Project

Dr. Mark G. Barkan, MBA, TRIZ Master

Knoxville, TN 37922, USA

Abstract

The financial/economic justification process has long been identified as the biggest obstacle to approval of many process and product improvement projects. While the new buzz word in business is innovation, in reality, very few innovative type projects survive the scrutiny of a rigorous financial analysis. In the last 25-30 years, the printed and electronic media have been flooded with a huge number of methods for evaluation of economic validity that look feasible for the development of solid financial argument in favour of project acceptance.

Some of the methods are, basically, set of policies that evaluate qualitative issues related to R&D projects. These methods lack quantitative thoroughness, but they may prove extremely effective in evaluating an investment in innovation type projects. On the other hand, several other methods were proposed that are exhaustive in nature, and require hard core quantitative data that is normally hard to retrieve or formulate. Thus, a decision maker, who is evaluating a potential investment in an innovation project, may have difficulty with choosing an appropriate evaluation method.

Then, there is often a need to select the very best investment opportunity from among a large number of proposals. Here again, quantitative methods are cumbersome at best and useless at worst.

In this paper, I will examine 3 most often used methods of calculating fiscal validity of an innovation project and offer, what I believe, is the one of the better ways to evaluate an innovation project by combining the quantitative and qualitative methods.

Key words: Risk Management, Return on Investment, Internal Rate of Return, Net Present Value, Financial Analyses, and Comparative Analyses.

1. Introduction

In a nut shell, there are two situations where TRIZ tools may be applied: 1) fire-fighting, when time is of essence and business demands fast remedies for an emergency; 2) new product/process development efforts, where TRIZ tools play ever increasing role. In the first case, the management is not overly concerned with financial or any other justification. Just fix it! The second case receives a very different treatment. Here, risk management rules. The risk management is approached not as a safety procedure but as a learning process. Managers know that no new business model or process or product is perfect from its inception. So they test its various components and their combinations—its customer value proposition, profit formula, key resources, and key processes—in controlled experiments in tightly circumscribed markets, learning as they go and making adjustments. However, in these situations it is prudent to exercise a more relaxed approach to the financials.

Before I dive into financial mumbo-jumbo I would like to point a difference between product and process innovation. In my article on the subject for the TRIZ-Journal, I described the differences between product and process innovation as follows:

2. Product and Process Innovation.

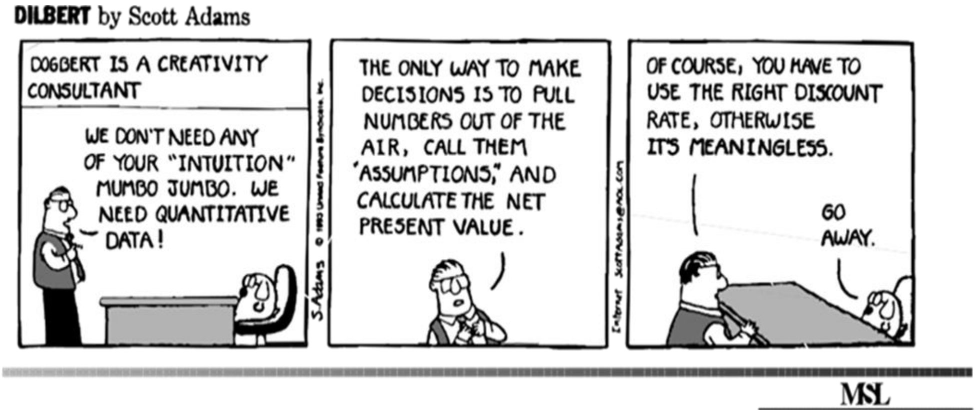
The primary goal of most innovation processes is an improvement in business health of an enterprise. With this said, we need to distinguish between product and process innovation. Although both are aimed at increasing bottom line, the former requires a different set of skills in that it deals with externally generated functional requirements.

While the latter deals with functional requirements generated internally. Thus, process innovation takes place in an easier controlled environment. Yet, it always lags behind product innovation. The silver bullet hopes of most sales/marketing managers are placed with product innovation. However, product innovation is usually disruptive since it is based on disruptive invention. On the other hand, process innovation is much easier to accomplish in a sustainable manner.

3. Selecting an accounting method

Based on the above, we may conclude that Process Innovation project may be justified with the conventional Financial Management tools. While Business Model Innovation project or Product Innovation project may benefit from more relaxed approach to financials. With this said, I will discuss more rigorous financial approaches – Internal Rate of Return (IRR), Net Present Value (NPV), and Return on Investment (ROI). These approaches have been perfected by the financial community as they have been used for many years. I will define ROI in greater detail as it is most used accounting method for an innovation project financial justification.

It is fare to say that long established practices used to manage budgeting, planning, forecasting, reporting and risk management are becoming increasingly complex. As a result, budget and finance professionals are being pressured to improve accuracy, efficiency, better controls, and auditability and to provide greater visibility into costs, resources, and performance which is not an easy task. Dilbert cartoon below illustrates, somewhat, the hurdles on the path of required financial precision.



4. Internal Rate of Return – IRR

The Internal Rate of Return (IRR) is the discount rate that generates a zero net present value for a series of future cash flows. This essentially means that IRR is the rate of return that makes the sum of present value of future cash flows and the final market value of a project (or an investment) equal its current market value.

Internal Rate of Return provides a simple ‘hurdle rate’, whereby any project should be avoided if the cost of capital exceeds this rate. Usually a financial calculator has to be used to calculate this IRR, though it can also be mathematically calculated using the following formula:

$$CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \frac{CF_n}{(1+r)^n} = 0$$

In the above formula, CF is the Cash Flow generated in the specific period (the last period being ‘n’). IRR, denoted by ‘r’ is to be calculated by employing trial and error method. Internal Rate of Return is the flip side of Net Present Value (NPV), where NPV is the discounted value of a stream of cash flows, generated from an investment. IRR thus computes the break-even rate of return showing the discount rate, below which an investment results in a positive NPV.

A simple decision-making criteria can be stated to accept a project if its Internal Rate of Return exceeds the cost of capital and rejected if this IRR is less than the cost of capital. However, it should be kept in mind that the use of IRR may result in a number of complexities such as a project with multiple IRRs or no IRR. Moreover, IRR neglects the size of the project and assumes that cash flows are reinvested at a constant rate. IRR is a simple way to chose among several projects.

5. Net Present Value – NPV

Net Present Value (NPV) is a formula used to determine the present value of an investment by the discounted sum of all cash flows received from the project. The formula for the discounted sum of all cash flows can be written as

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}$$

$-C_0$ – Initial investment
C – Cash Flow
r – Discount Rate
T – Time

When a company takes on a project, it is important to calculate an estimate of how profitable the project will be. In the formula, the **$-C_0$** is the initial investment, which is a negative cash flow showing that money is going out as opposed to coming in. Considering that the money going out is subtracted from the discounted sum of cash flows coming in, the net present value would need to be positive in order to be considered a valuable investment.

This method requires very clear crystal ball in order to assume future cash flows.

6. Return on Investment – ROI

The issue of ROI, as applied to TRIZ project, is a complicated one, at best. The uncertainty of the outcome in terms of expenses and revenues does not allow using the standard formula for ROI calculation. The standard formula states:

$$\frac{I_{no}}{S} \times \frac{S}{A} = ROI,$$

Where:

I_{no} - Net Operating Income (Margin)

S - Total sales

A - Average operating assets

This formula was first adapted by DuPont to describe return on investment in terms of assets and not just margins. It is a derivative from a more general formula for ROI:

Margins x Turnover = ROI

According to ROI formula, profitability may be improved in three ways:

- By increasing sales
- By reducing operational expenses (variable costs)
- By reducing assets (plant and equipment)

It appears that the sales figure is neutral, since it is present as denominator in the margin computation and as numerator in the turnover computation. It could be canceled out, but is not for two reasons. First, this would tend to draw attention away from the fact that the ROI is a function of two variables, margin and turnover. And second, it would tend to conceal the fact that a change in sales can affect either the margin or the turnover in a company. This is consistent with the Ideality concept. By increasing sales w/out increasing expenses the company will achieve higher margin, conversely, increase in sales w/out increase in total assets will also increase turnover.

In addition, we need to consider whom we are dealing with in terms of fiscal responsibility. Is the manager, we are dealing with, responsible for Cost Center, Profit Center, or Investment Center.

Cost Center is any responsibility center that has control over the incurrence of cost. This center has no control over either the generating of revenue or the use of investment funds.

Profit Center has control over both cost and revenue. However, it does not control over how the investment funds are used.

Investment Center is any responsibility center that has control over cost, revenue, and also over the use of investment funds. That is where the money spending decisions are made.

Every one of these centers will require an individual strategy in promoting TRIZ project. When we are dealing with technical people we are dealing with cost center, which does not make investment decisions.

Based on the above and considering every potential customer's particular situation, we can put together a believable scenario for ROI when we talk about TRIZ project. We can stress either reduction of operational expenses (costs), reduction in total assets, or increase in sales. The hard numbers are only possible once we learn the aspirations of a particular customer and their markets and finances. In many cases it may be possible to collect necessary information to come up with a convincing number of monetary benefits associated with proposed project.

Although ROI is widely used for evaluating project performance, it is far from being a perfect tool for the following reasons:

ROI tends to emphasize short-run performance rather than long-run profitability. Thus, in an attempt to protect short-run ROI, a company, or a manager in charge, may be motivated to reject otherwise profitable opportunities.

ROI is not consistent with the cash flow models, which are normally used for capital expenditures analysis.

ROI may not be fully controllable by the business center manager due to the presence of committed (allocated) costs. Managers are sensitive to the fact that, due to inability to control ROI, their performance would be difficult to distinguish from the performance of the business unit as an investment center.

In addition, the implementation of many R&D projects is so far into the future that it prevents any reliable ROI calculation to support investment. Especially it is true in a case where an innovation will necessitate major revamping of the asset base, plant and equipment, as it presents a major problem of justifying capital expenditures for something uncertain.

To overcome these problems, many companies use multiple criteria in evaluating a project rather than relying on ROI as a single measure. Other criteria used are, but not limited to:

- Growth in market share
- Increases in productivity; improved functionality w/out increase in costs
- Product/process innovation
- Ability to expand into new and profitable areas

The situation becomes even more complex when there are several candidates for R&D dollar. Then, it is necessary to perform cash flow analysis and to determine NPV (net present value) of every option.

All the discussion thus far brings us to realization of the need for the ability to select a viable project. Can TRIZ tools aid potential customer in this process? To answer this question we need to discuss two drivers of innovation. One is the market and the other is the technology. Experiences of many companies clearly indicate that technology driven innovation is most often doomed to fail. Why? Because in most cases the new technology is developed by a start up company, which does not have sufficient capitalization to survive the time required for generation of enough interest to realize sale. Or the new technology may be rejected by the market as premature or irrelevant.

On the other hand, market driven innovation is a winner in most cases. Here we face a problem of different nature. A company may get beat to the punch bowl by the competition. This will happen every time when market trends are not recognized in a timely manner or when the investment in viable R&D project is delayed. However, based on recognized market direction and our ability to rapidly develop/improve a system to meet future market requirements, we can engage in a technical project, which will have an appropriate goal easy to quantify in terms of ROI.

The objections for this approach may stem from what may seem as technology driven successful innovations, especially in case of computer technology. In this case, however, we have a combination of advance of solid-state technology, which enabled miniaturization of computers, and market need for portable computing devices, which originated with hand held calculators.

The next important issue is how to approach a forecasting project for understanding of market direction. The difference in approach is dictated by different position of company's product with reference to end user. The greater is the distance between a product or process and the end user the more expensive is the innovation process. Conversely, the less complex the system under consideration, the larger is the area of research for determination of several future steps of development/evolution.

References:

1. Steve Culp, "Risk Management Can Stimulate, Rather than Deter, Innovation" – Forbes 1/7/2013
2. Mark Barkan, "Risk-Free Business Innovation" – The TRIZ-Journal, August, 2006
3. Eugene F. Brigham, Michael C. Ehrhardt, "Financial Management-Theory and Practice", Cengage Learning, 2010
4. Daniel Linman, "Justifying a Project Through Analysis", MyManagemenGuide.com, October 6, 2011
5. Michael Sack Elmaleh, "Do Accounting Rules Discourage Research & Development?", Understand Accounting – Mercifully Brief Accounting Search Engine

Author (co-author) to contact: Mark Barkan, barkan@matriz.org

TRIZfest-2014

„Meeting With a Miracle“ as a Pedagogical Tool

Anatoly Guin

“Education for a New Era”, Moscow, 125252, Russia

Abstract

The educational system, especially grade school education, undergoes crisis all over the civilized world. One of the main indicators of this crisis is loss of children’s motivation. This article discusses the possibility of purposeful use of the emotions of surprise as a teaching tool – a means of motivation. TRIZ founder Genrich Altshuller noticed: in the biographies of the Creative Personalities of high level it can be seen that in the childhood they experienced great surprise. This surprise, "encounter with a miracle", motivated their cognitive activity. In personal conversation Genrich Altshuller suggested to the author of this article to start developing themes "surprise as a way to motivate children to learn." This article introduces the reader to some of the results of this development.

Key words: hypothesis, astonishment, motivation, instrument.

1. First surprise, then teach

What does an adult do when he is given answers for the questions he did not ask, when he is told something he has no interested in? Does he cover his ears with his hands? Not necessarily. Polite person can listen just because he doesn’t want to offend a speaker. A subordinate can listen to his boss just because “evading this honourable duty is fraught with…” He will listen but strain himself to understand, remember or actively join in a conversation – he will not. Roughly the same thing happens to the children in the classroom, when there is no interest.

Problem: The present system of education is based primarily on the fact that students are given ready-made answers to the questions they did not ask.

Real knowledge, free and effective, begins with questions that man asks himself. And where is the beginning of this Self-inquiry? The author believes that the process of Self-inquiry begins with a surprise. If so, the new educational system should include a process of surprise of a student as a mandatory element, as a tool or technology for motivating said student.

2. An ideal student

Founder of TRIZ (Theory of Inventive Problem Solving) Genrich Altshuller suggested that thirst for knowledge of the child is the result of a strong surprise, delight - he called it "a meeting with Miracle." Altshuller’s students studied the biographies of eminent personalities, trying to test this hypothesis. V. Berezina examined dozens of childhood of great people, based on the resulting catalog, the book was written.[1] Lamarck and Darwin, Vernadsky and Kropotkin, Pasteur and Chizhevsky, Schliemann and Einstein - in the biographies of these and many other brilliant people we can find "a meeting with Miracle.”

In early childhood the father showed to Albert Einstein a compass. For a long time he examined this exotic thing with concentration. The kid was struck that the small hand always "knew" where the parts of the world were! It was a riddle which he contemplated for a long time. The conclusion was: "I think that around this hand there is something that pushes it". [2]

To Heinrich Schliemann, future archaeologist who dug out legendary Troy, the father presented the book "The World History for Children". The boy examined an illustration for the story about Trojan War. “Is it true that ancient Troy had such big walls?" Little Heinrich was struck by the fact that a huge fortress has disappeared and no one knew its location. And he set a goal to find Troy. In 49 years, a successful entrepreneur who knows many languages, including Greek, sells his business and equips an expedition in search of Troy ... [3]

Ivan Efremov was shocked by Jules Verne's book. “When Vanya was six he became the first reader of his father’s library.” The book "Twenty Thousand Leagues under Water" made resounding impression. Future palaeontologist and writer were "infected by popular science book bug”. In these books he found his future vocation. [4]

A good book can be a source of inspired passion for knowledge, if the pages of the book contain that which may startle. Of course, no one can guarantee that even the best book will be a particular source of inspiration for a particular child. But, maybe, we should fill textbooks with surprising and interesting facts, stories and interpretations? Especially, considering the fact that the real science is full of them.

The author believes that it can be done. The modern technique of delivering training material (in textbooks, lectures, experiments and so forth) must include surprise as motivating element of cognitive process. Motivation of knowledge is much stronger and more effective if it is caused by the process of cognition, rather than external causes (a driver's license or a diploma of higher education) or forceful pressure. Want to teach effectively - first surprise, "Light the torch!" "Very early in our lives we cease to be surprised, – lamented Y. I. Perelman[2], –we lose precious ability which induces to be interested in the things, which aren't directly affecting our existence; that vividly occupied us when "... all impressions of life were new to us", ceases to draw attention, becoming habitual". [5]

The student who said "Wow!" to himself, who wishes to examine, to understand the reasons of astonishment is an ideal student. He doesn't need to be forced and punished, there is no need to convince and prove to him the value of knowledge.

3. Knowledge through an open problem

I witnessed the following situation numerous times: the teacher comes to the class and announces to students: today we have very interesting subject! Write down: we will study … Next, any of grade school subjects follows: Archimedes’ law; magnetic properties of substance; lake’s biocenosis, city ecology …

The teacher may be passionate about his work. And the theme is really interesting - but not for children.

A lesson, where the teacher challenges the students, offering them to solve an open problem, looks very different.

Teacher:

[2] Yakov Perelman – the *outstanding writer of popular science, the author of many books, by which the generations of the Soviet scientists and engineers grew up.*

- I'll tell you a story. An invention claim came to Patent office. The author proposed the use of a powerful electromagnet to pull hot iron billets out of the oven. But a patent for the invention was not granted. Why so?

Children:

– Perhaps, the billets too heavy?

– Oh, no, as a last resort, it’s not difficult to increase a magnetic field.

– Or perhaps it’s too expensive?

– Or perhaps the claim was wrongly worded?

Five-six more such "And perhaps...?", then silence – however, not for long. Seta draws something on paper with concentration, Nick rubs his forehead with a palm, and Dan stares at the ceiling. But Eugene jumps up: "The heated iron isn't magnetic!" The silence explodes. After short, but intensive discussion the hypothesis is accepted. The teacher rises to speak:

– In reality, iron, cobalt, nickel and other magnetic substances at a certain temperature – physicists call it Curie's point – lose their magnetic properties. This effect wasn't considered by the unsuccessful inventor. Write down a new subject: magnetic properties of substance …

Thus, through an open problem, the teacher "walked" the children into a new subject. Children didn't notice as this subject became of interest.

There is a huge number of puzzles and paradoxes, that TRIZ teachers learned how to formulate into open problems, in science, technology, and even in everyday life. This provides one with the opportunity to surprise, to give students a sense of wonder at the various school subjects and in almost every lesson. Moreover, it is the key to solving the fundamental contradiction of mass education.

4. A case from practice

I wondered how to conduct a lesson on "electrostatic induction". I vividly imagined class. Here sit 30 teenagers of different sexes. Peter thinks about Mary. Mary thinks about Alex. Serge wants only one thing for sure - that he is not asked. Anyone of them thinks about electrostatic induction? No one! And who asked me about it? No one! Here, I will enter the classroom and write the topic on the board. Whom it will inspire? Nobody...

And it saddened me, and I began to think whether there is a way out of this situation. How to light the guys’ interest? And what, of things I know, is the most interesting about electrostatic induction? And I came up with something.

...

Fig. 1 Illustration to the problem

“Children!” – I began a lesson. – I will tell you a life story. This case was described in the newspaper and occurred near our city. Imagine a high hill on which the cow (see Fig. 1) is grazing. It was raining, there were clouds in the sky, thunder and lightning. And suddenly after the next lightning strike the cow fell dead. Try to determine why the cow died – what happened?"

After a short discussion, children generated hypotheses:

– a lightning hit the cow;

– a lightning hit a pool near a cow, and electric current killed her;

– the cow died of fear;

– the cow slipped and fell;

– it died of old age, and the lightning –is a simple coincidence;

– a lightning struck a tree, the tree fell on the cow …

The first 7-8 hypotheses were born quickly, 2-3 more – with great difficulty.

I interrupted them: "I must tell you that nobody called the correct cause of animal’s death". On faces surprise – and what occurred actually? Now Peter, Mary and Alex, and also all the others, have one thing on their minds: how the death of the cow is connected with lightning?

I declare the topic of today’s lesson: "Electrostatic induction". "Now I will explain you the essence of this phenomenon for about 10 minutes. The one of you, who will guess first how it is connected with our task, will receive a great ataboy! Let’s start …"

Now the attention of the entire class is riveted on me …

5. Contradiction of mass education

Every child, a student, who comes to class, is thinking about something of importance to him/her. Everyone, at this point in time, has his/her own interest, his/her own question. But we, the teachers, in the traditional structure of classroom learning don’t really consider this. Yes, we are in many ways trying to "tune" the students at the beginning of the lesson, using oral questioning, analysis, or homework, or anything of the sort from the arsenal of pedagogical methods. But this is clearly not enough for the active participation of students in the lesson. To do this, there is only one right way - to awaken interest.

At the lesson on electrostatic induction I used a problem, which was designed on the basis of a newspaper article. Similar problems with research or inventive content we call open problems. Open problems – are the means with which the interest is awaken. Today, we[3] checked it in practice with various audiences – from elementary school age children to adult professionals, teachers and engineers.

Open problem, is becoming an element of the learning process, an instrument for resolution of the fundamental contradiction: on the one hand, each student comes to class with his/her interest; on the other hand, for the effective learning the entire student body should have a common interest in specific topic of the lesson.

6. Fuel for cognition

In earlier times, students’ diligence was often ensured by force. "Ears of a child are on his back" - a proverb Egyptologists found on one of the clay tablets in an ancient Egyptian library.

[3] *Specialists of public laboratory “Education for new Hera”.*

Today, in civilized countries, coercive methods of teaching can't be used. Yet, any new methods of motivation are rarely practiced. This is one of the main reasons for the educational system crisis of the grade school.

Teacher, who has mastered skills of surprise, doesn't experience discipline problems , he doesn't need to force students to study. Surprise is the fuel for cognition. And an open problem is not the only way to surprise. For example , the teacher comes to the class dressed as the ancient philosopher , Aristotle, and shares his ideas about the world. A task for the children is to try to convince the "Aristotle" that his ideas are wrong , discuss new scientific concepts . And all of a sudden, and much to the surprise of children, it turns out that they can't do it! Aristotle "breaks" their arguments and remains unconvinced. This play is a great prelude to a lesson on philosophy.

7. Basic proposition and conclusions

1. Surprise is a key motivator of cognition.

2. Development of society leads to the repudiation of coercive motivation for learning.
3. Modern education system doesn't keep up with the requirements of a changing world. Modern didactics doesn't provide tools for teachers helping them to surprise students as a way of triggering motivation.

4. Educational Reforms that do not involve a change of didactics, methods and techniques of knowledge flow, represent no more than a jump from the day before yesterday to yesterday.

5. We need new didactics, corresponding to the modern teaching methods and techniques, including tools of surprise.

6. Elements of such didactics have already been tested in TRIZ-pedagogy.

Literature

1 . Berezina V.G., Vikentyev I.L. Modestov. Childhood of creative people: meeting with a miracle. Mentors. Worthy purpose. Version 1.0. S-item: Bukovsky's publishing house, 1995. 60 pages.

2 . Lviv V. Albert Einstein's life. M.: Young guard, 1959. Page 6.

3 . Meerovich M. Schliemann. M.: Children's literature, 1966. Page 15-19.

4 . Chudinov P. K. Ivan Antonovich. Efremov. M.: Science, 1987. Page 13-22.

5 . Perelman Ya.I. What is entertaining science? Citation from: Schukina G. I. Problems of informative interest in pedagogies. M.: Pedagogies, 1971. Page 22-33. (http://pedagogic.ru/books/item/f00/s00/z0000008/st160.shtml).

Author (co-author) to contact: Anatoly Guin, Guin@trizway.com

TRIZfest 2014

Multi-Screen Analysis for Innovation Roadmapping

Valeri Souchkov

ICG Training & Consulting, 7511KH Enschede, The Netherlands

Abstract

The paper presents an approach to enhance innovation roadmapping with the use of a tool "Multi-Screen Analysis" (MSA). MSA is based on extracting changes of the functionality of a system by exploring its historical evolution and discovery of contradictions emerging during the system's evolution. Such information helps to identify and structure resources for future evolution of the system.

Keywords: Multi-Screen Analysis, System Operator, Innovation Roadmapping.

1. Introduction

1.1. Multi-Screen Scheme of Thinking (System Operator)

G. Altshuller originally presented a Multi-Screen Scheme of Thinking (also known as System Operator") in [1]. He considered a capability of seeing the world as a system, at many levels, or "screens" as one of the key features which distinguishes between thinking of a talented inventor (or any talented person who uses creativity to produce positive changes) and thinking of a person who is not engaged to creative activities. He proposed to use System Operator as a tool for developing creative imagination.

A basic model of a System Operator is well known in TRIZ and is shown in Fig. 1. It consists of nine boxes, or "screens" which present: i) a specific system of the latest generation (central box), ii) the upper and lower boxes representing its supersystem and subsystems, as well as boxes representing the previous and the future generations of the system given including its past and future supersystems and subsystems. Nine boxes are the minimum number; while more boxes can be added along any axis as soon as a more detailed study is required.

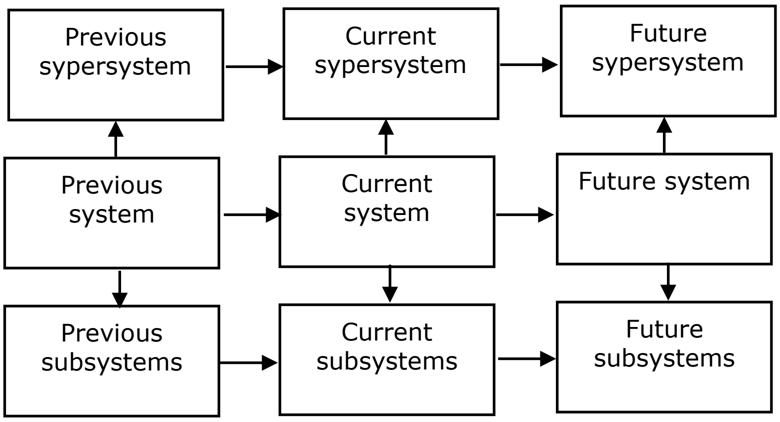


Fig. 1. A basic Multi-Screen Diagram of Thinking (System Operator)

A core idea behind System Operator is that when we attempt to effectively forecast future evolution of a system it is not enough to focus on the system only without taking into consideration information about its past and future changes in its supersystem which are expected to produce impact on the system's evolution. The boundaries of the system under analysis thus have to be expanded along both the time and space axes. One can only produce a more or less reliable forecast by taking into account how evolution of the system will impact evolution of its supersystem and, in return, how evolution of supersystem is going to impact evolution of the system. In addition, it is important to understand what factors can be considered as driving evolution of the system therefore one has to analyse connections between the past generations of the system and its latest generation to extract this information.

1.2. Using System Operator as a Tool for Innovation Roadmapping

Although System Operator is a very valuable tool for developing creative imagination skills, lately it has been used in a broader context for producing innovative ideas for actual innovation projects. However a general problem with using System Operator as a tool for producing new ideas is the lack of guidance how it can be used and how new ideas can be produced.

Motivation to use System Operator for dealing with pragmatic innovative tasks resulted in the development of a number of ideas and methods which propose to deploy Multiscreen Thinking in its existing form as a tool for producing new innovative ideas [2-4]. Another research work proposes to extend the basic model of System Operator with new dimensions and parameters [5]. Although increasing complexity of System Operator might lead to increasing its capabilities, a problem is that even using its basic model creates certain difficulties since it requires upgrade of a thinking paradigm of majority of people. It is however not easy to achieve.

One of the potentially promising applications of System Operator resides within innovation roadmapping [6] which targets the development of a shared vision of the future of a specific system presented in form of time-based scenarios. Today a number of approaches to innovation roadmapping are known which include various supporting means such as technical tools and best business practices. The TRIZ tools can also be effectively used for innovation roadmapping, for example, the Laws and Trends of Technical Systems Evolution or Function Analysis and Trimming. In turn, System Operator can also be used to support the analytical stage of the innovation roadmapping process.

2. Multi-Screen Analysis

2.1. Approach

One of the primary challenges during the process of innovation roadmapping is a lack of a structured methodological support for gathering and processing information. A problem is rather similar to the problem inherent to a traditional non-systematic approach to inventive problem solving: without a proper guiding method, too many trials and errors are produced and it is not clear what to focus on. In addition, there is a high risk of producing wrong results. In TRIZ such a problem is solved by narrowing the task through abstract modelling and reducing search space by using empirical rules.

Multi-Screen Analysis (MSA) uses a similar approach to structure the process by dealing with a number of abstract concepts such as functions and contradictions which can be considered as driving forces behind evolution of any man-made system. MSA is therefore based on the TRIZ philosophy to forecast future innovations by exploring current and future problems. However if such tools as for example Function Analysis provide useful information about functionality-related problems of the latest generation of a system, Multi-Screen Analysis helps to identify problems and challenges which relate to the dynamic changes occurring during evolution of the system towards its latest generation.

MSA thus focuses on those problems that have been created during the process of evolution to a more innovative generation of a system. The primary subject of study by MSA is exploration of issues emerging because of transition from the past generation of a system towards the latest generation.

The goal of MSA is to identify the following sources of problems and challenges:

1. Functions that are available but not delivered with the desired degree of performance.
2. Missing functions that are required by supersystem.
3. Functions that will become necessary to adapt the system to its future supersystem but not delivered by the current system yet.
4. Contradictions that still remain unsolved.
5. Contradictions that will emerge between the current system and its future supersystem.

To extract such problems it is proposed to perform a study of effects produced by innovative changes experienced by a system during transition from its past generation(s) towards the latest generation. In principle, an idea of the analytical part of MSA is similar to the process of "genetic analysis" proposed in [7] which is used to discover problems that emerged during transition between several generations of a system. Besides extracting the existing problems and challenges, MSA also includes a creative phase to discover problems that might be experienced by the system in future.

The output of MSA consists of two lists:

1. The list of problems and challenges experienced by the latest system generation.
2. The list of problems and challenges the system will experience in the future.

As clear, some problems and challenges will belong to the both lists. A process with MSA is shown in figure 2.

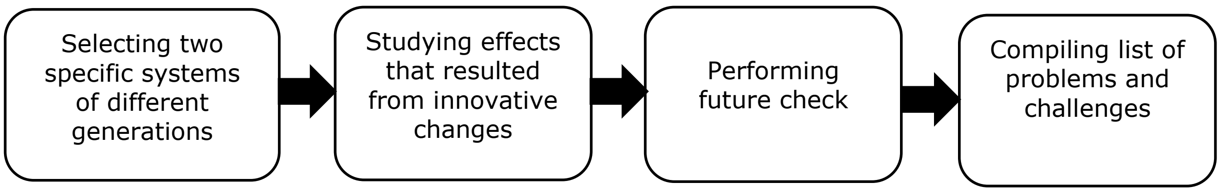


Fig. 2. A process with Multi-Screen Analysis

2.2. MSA Checklists

In order to perform MSA, a technical system of the latest generation and a system of the previous generation are selected. In a situation when there are a number of competitive systems available, a choice of a specific latest generation system depends on the matching interests of all stakeholders involved.

To perform analysis, a component model of the technical system is used which is comprised of a number of subsystems to list all the subsystems of two systems. Certain subsystems can be aggregated to create bigger subsystems if necessary in order to simplify the component model. It becomes useful for those subsystems that have not experienced innovative changes. Alternatively, any subsystem of a more complex system can be taken for analysis as a standalone system.

MSA consists of a number of questions, which are divided to four categories to gather the following information:

1. Information about impact of innovative changes of subsystems.
2. Information about impact of newly added subsystems.
3. Information about impact of subsystems which ceased to exist.
4. Information about impact that will be produced by future supersystem.

Below we consider examples of specific questions in each category, which are used to gather information for MSA.

2.2. Specific MSA questions

The first category of questions concerns changes, which occurred in the system with respect to its subsystems. In MSA only innovative changes are a matter of interest.

A number of questions are asked about each subsystem that experienced significant change in order to gather information on the following subjects:

1. If a specific change removed any useful function(s).
2. If a specific change added new useful functions(s).
3. How did a specific change negatively affect quality and robustness of the subsystem or the entire system.
4. How did a specific change negatively affect performance of the subsystem or the entire system.
5. How did a specific change negatively affect usability of the subsystem or the entire system.
6. How did a specific change negatively affect life-cycle of the subsystem or the entire system.

After performing the study, similar information is gathered about effects resulting from adding new subsystems to the system and from removing specific subsystems from the system. As a result, we obtain three groups of answers which summarize all the effects produced by innovative changes of the system.

After obtaining responses to the questions from categories 1-4, one can make conclusions about:

1. Parameters of quality, performance and usability that require improvement.
2. Functions that are not delivered yet with the desired degree of performance.
3. Functions that are missing in the system.
4. Contradictions which still exist in a system.
5. Contradictions which were created by a transition from the system of previous generation to the latest generation system.

The final, fourth category of questions deals with future changes of supersystem. If previous four categories of questions use information which is readily available, the fifth group of questions require imagining how the supersystem is going to change within the proposed period of forecast. Answering the questions of this category requires performing a creative phase first to develop an image of a future supersystem and creating a list of future supersystem changes. After all the ideas about changes in the supersystem have been produced and accepted, the following questions are asked:

1. Will future supersystem’s changes demand new functionality and if yes then what functionality?

2. Will future supersystem's changes require removal of any of the existing subsystems and if yes then what subsystems?
3. Will future supersystem's changes eliminate the existing contradictions and if yes then what contradictions?
4. Will future supersystem's changes create new contradictions and if yes then what contradictions?

3. Case: Multi-Screen Analysis of an Umbrella

In this section we present a fragment of a project which involved MSA to "multiscreen" the evolution of umbrella (Figure 3) at the analytical stage of the innovation roadmapping process.

Fig. 3. Selected previous generation and modern umbrellas

The first step is to analyze which components belong to the subsystems and supersystems of both umbrellas (Figure 4).

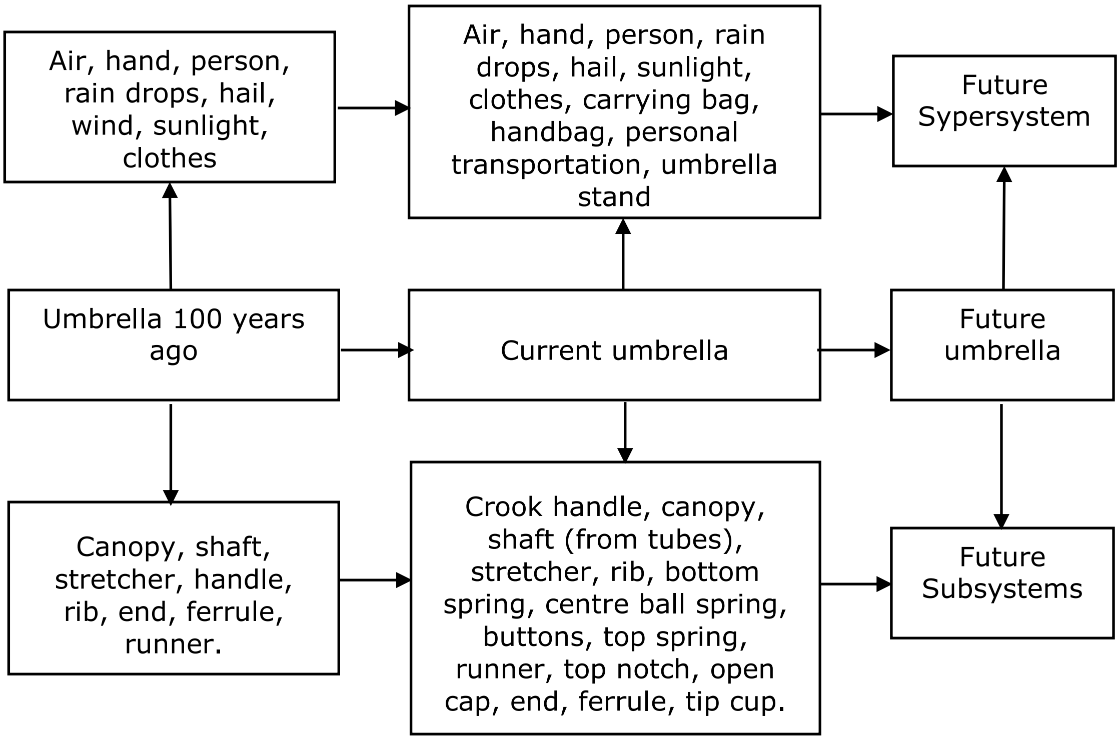


Fig. 4. Analysis of two umbrellas of different generations by identifying their past and current subsystems and supersystems.

The next step is to select each subsystem which was changed and describe what innovative changes it experienced. Against each change all questions mentioned above in the first category of MSA checklists have to be answered and translated to contradictions. The results of this study for the umbrellas's subsystem "shaft" are shown in Tables 1 and 2. In the example we only included several changes while there were more changes, for example we omitted the fact that wood as a material of the shaft was replaced with metal (or plastic).

Table 1: Exploring functionality change

Shaft	Innovative Changes		
	Became telescopic	Became hollow	Contains openings
Removing useful functionality	none	none	none
Adding new functionality	- Provides extension and contraction of the shaft.	- Provides space for springs. - Provides space for inserting the other tube of the shaft.	- Provides open space for buttons
Affecting existing functionality	- More difficult to open	none	none
Affecting existing quality	- Easier to break	- Easier to deform	- Water can get inside - Buttons can stuck
Affecting existing performance	- More time to open the umbrella	none	none
Affecting lifecycle	- More difficult to assembly - More difficult to utilize - More difficult to produce	- More difficult to produce	- More difficult to produce

Table 2: Exploring contradictions

Shaft	Innovative Changes		
	Became telescopic	Became hollow	Contains openings
Affecting the existing contradictions	- Shaft should be long to comfortably use the umbrella and short for convenient transportation	- Shaft should be heavy to resist forces of wind and rain and lightweight to provide convenient use	none
Creating new	- Shaft should include	- Shaft should be	- Shaft should be sealed

contradictions	one piece to be easy assembled and maintained and many pieces to provide telescopic effect - Shaft should be complex to enable telescopic effect and should be simple to prevent from being easily broken - Shaft should be complex to enable telescopic effect and should be simple to easier produce and recycle - Shaft should include a number of pieces to stay short and to stay one piece to avoid applying too much effort to open - Shaft should include a number of pieces to stay short and to stay one piece to avoid spending more time to open	hollow to provide telescopic effect and contain other parts and non-hollow to avoid deformation.	to prevent water from getting inside and open to let buttons move - Openings have to be narrow to not let rain getting inside and wide enough to avoid the buttons from being blocked inside. - Shaft should contain openings to provide path for buttons and do not contain openings to be easier to produce

A study of tables 1 and 2 results in formulation of the following problems and challenges expressed in terms of contradictions (only opposing demands are shown):

1. The shaft should long and short.
2. The shaft should be heavy and lightweight.
3. The shaft should be complex and simple.
4. The shaft should be hollow and non-hollow.
5. The shaft should be sealed and contain openings.
6. The openings in the shaft have to be narrow and wide.
7. The Shaft should contain openings and do not contain openings.

Note that the first two contradictions refer to both generations of umbrellas while the remaining contradictions are only present in the umbrella of the latest generation. Although transition to the telescopic shaft partly resolves the contradiction concerning the length of a shaft, it is still not fully solved and therefore it was brought to the list of existing problems and challenges.

Similar tables can be created and conclusions are made for other two categories of questions dealing with added and disappeared subsystems listed in Section 2.2.

Regarding the third step of MSA Process “Performing future check” (Figure 2), it refers to the fourth category of questions presented in Section 2.2. Table 3 shows a fragment of extracted challenges at this step.

Table 3. Challenges revealed at the stage of Future Check

Future change	Impacts			
	System	Subsystem(s)	New Function (s)	Contradictions
Water-proof clothing	Umbrella disappears. Its function is transferred to clothes.	The canopy should not protect from rain any longer. Only protection from sunlight is required.	Function protect from rain/hail disappears	
City districts under rain/hail protecting cover	No umbrella is needed			
Smaller carrying bags	The whole umbrella should become as tiny as possible (e.g. to be carried in a pocket).	Canopy, shaft		All large parts of the umbrella should be big to protect from rain and enable convenient use and small to become portable
Climate control / eliminating rain in populated areas	Umbrella only for the use outside cities		Protecting from rain outside cities	Umbrella does not exist while in a city and emerges only when outside the city.
Shorter travel times in open air	No impact	No impact		
…	…	…	….	…

After all information has been gathered and analyzed, all discovered problems are brought together and ranked to identify innovation priorities. Ranking the problems is not part of MSA, any available ranking method can be used.

4. Conclusions

In summary, MSA provides the following:

1. Observing and mapping problems and changes were experienced by a system under analysis with respect to the selected past system generation.
2. Learning what factors negatively influenced the system’s development from both subsystem and supersystem perspectives.

3. Understanding what we want to change and improve in order to create a system with a higher degree of ideality.
4. Formulation of problems to solve to develop a future generation of a system.

It is obvious that MSA enables performing system analysis from a single perspective only: exploring what problems and challenges were created by a transition from the past generations of a system towards the latest generation of a system. Therefore further MSA development will be focused on integration of MSA with other methods of analysis and innovation roadmapping.

References

1. Altshuller G. *Creativity as an Exact Science*. Moscow, Moskovskiy Rabochiy, 1979 (in Russian)

2. Frenklach G. Efficient Use of the System Operator, *The TRIZ Journal*, January 1998.

3. Seredinski A. A Complementary Possibility of the 9-Screen Diagram. *Proceedings of the TRIZ Future 2001 World Conference.*, Bath, UK, 7-9 November 2001.

4. Mann D., "System Operator Tutorial 1–4," (series of articles), *The TRIZ Journal*, September 2001 - January 2002.

5. Khomenko N. *An Extended Scheme of Multi-Screen Thinking*. Last seen: http://www.otsm-triz.org/en/node/367#1 (in Russian).

6. Simonse.L., Buijs, J. & Hultink E. Innovation roadmapping: Building a theoretical framework from multiple cases of industrial firms. In *Proceedings of the 19th International Conference on Engineering Design (ICED13) Design For Harmonies*, Vol. 3: Design Organisation and Management, Seoul, Korea 19-22.08.2013 pp. 269-276

7. Gerasimov V., Kalysh V., Karpunin M., Kuzmin A. & Litvin S. *Main Principles of a Method of Performing Function-Cost Analysis*, Moscow, MP Inform-FSA, 1991 (in Russian)

Author (co-author) to contact: Valeri Souchkov, valeri@xtriz.com

TRIZfest 2014

Novel Approach to Categorization of Functions That Engineering Systems Perform

Oleg Feygenson[a], Jun-Young Lee[a], Naum Feygenson[b]

[a]*VIP Center, Samsung Electronics, Suwon, 443-742, Republic of Korea*

[b]*Samsung SDI, Suwon, 443-803, Republic of Korea*

Abstract

This paper proposes a new approach for function modeling which is sufficient for describing complex engineering systems and revealing their function disadvantages. At the same time it is simple enough and not time consuming.

The approach includes:

- Detailed description of time and space where each action (the verb in function formulation) is performed. Such description can be done according to recommendations of the Advanced Function Approach (AFA).

- Basic assumption is that majority of functions that engineering systems perform can be described with a limited set generalized (underlying) functions formulated according to AFA.

Those suppositions have been substantiated logically and then proven statistically based on analysis of the data available.

Keywords: Advanced Function Approach, Function Analysis, Base / Underlying Functions.

1. Function Analysis in Modern TRIZ

Function Analysis, as defined in the modern TRIZ, is an analytical tool that identifies functions, their characteristics, and the cost of System and Supersystem components [1]. The goal of Function Analysis is to identify the system's disadvantages such as harmful functions, insufficiently or excessively performed useful functions, excessive cost of components. As it was proposed recently, the wrong place and time of performing functions, and the absence of the required useful functions can be also identified using AFA [2].

Function Analysis is the most developed and formalized analytical tool in the Modern TRIZ. That is why it does not require excessive time and intellectual effort from a researcher to get deep understanding of how the system under analysis works and what its function disadvantages are.

However, the lack of complete recommendations for selecting the most appropriate function(s) still exists. Till now, there were several attempts to address this issue [1-4], but most of them are used by their developers only. Usually, these attempts contain recommendations that make procedure of Function Analysis more complicated but do not really enhance its output. The recent fundamental research published by Yu.Fedosov [5] recommends “the most simple and obvious way of formulizing the procedure of formulating functions” – choosing the appropriate function for the current situation from “the list of elementary functions.” This empirical study [5] is based on the representative statistical data taken from the TRIZ consulting projects successfully performed at different engineering and scientific areas.

Another approach for formulating functions of the system’s components is based on application of detailed algorithms. The first algorithm for formulating functions was proposed by V.Gerasimov and S.Litvin [1]. Recently, A.Kynin and A.Priven [4] developed an algorithm for selecting the elementary functions from the matrix 4x4x4, which simplifies and standardizes the procedure reducing the risk of erroneous formulations.

The current paper focuses on hybridization of two approaches mentioned above. As a result, it allows us to propose a novel approach of performing Function Analysis that is simple enough and not time consuming but still sufficient for describing complex engineering systems and revealing their function disadvantages.

2. Novel approach to categorization of functions. Main assumptions.

“One should use common words to say uncommon things” Arthur Schopenhauer

The logic of this research follows the hypothetico-deductive method of creating scientific theories 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 approach suggested is based on two flowing statements:

· According to recommendations of Advanced Function Approach (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 which 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 the concrete empirical data.

Thus, we can formulate a main assumption: When AFA format of function description is utilized, the vast majority of actions (the verb related part of 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 joint;**

· **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.

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

3. Validation of the main assumptions.

"Knowledge is a process of piling up facts; wisdom lies in their simplification."

Martin Henry Fischer

The first version of "Elementary Functions" Handbook proposed in [5] is based on statistical approach: 32 function models of real complex engineering systems operated in different industries were analyzed; in total 256 components that perform 2132 functions were considered.

The proposed version of handbook has been used for our assumption validation. We substituted each function in the Handbook with one of the base/underling functions proposed above and parameters of performing this function. The results of substituting each elementary function are shown in the Table 1.

Note: we have not substituted the functions that are statistically used in function models very rarely – less than 1% of usage in the models analyzed [5]. In some cases, it was necessary to use several base functions in order to substitute a single elementary function presented in the Handbook.

Table 1: Suggested substitution of the elementary functions with the base/underlying functions described in AFA format

##	*Elementary Function*	*% of usage*	*Suggested substitution with the base functions*
1	To move	18,31%	To move (to/from the specific place; in the specific time; with specific the speed/acceleration)
2	To heat / to cool	16,28%	To move heat or thermal field (in the certain direction / to the specific place; in the specific moment of time) To hold heat or thermal field (in the specific place)
3	To accelerate / to brake	10,54%	To move (with the variable parameter speed) / to stop (at the certain place within the specific period of time)
4	To hold	10,02%	To hold
5	To wear	4,85%	To remove/to separate particles or fragments of materials
6	To gather	4,38%	To hold (in the specific place) To move (to the specific place)
7	To form	4,00%	To move material (in the specific place)
8	To measure	3,53%	*Out of the scope of this study*
9	To press / to stretch	2,97%	To move
10	To destroy	2,96%	To separate / to remove parts
11	To direct	2,73%	In AFA format function “to move” contains direction through the place of performing function.
12	To part	2,64%	To separate / to remove parts
13	To oxidize	2,16%	*Out of the scope of this study*
14	To join	1,88%	To move (until a physical contact with other object(s) occurs); to hold (in the definite place)
15	To evaporate	1,60%	To remove particles (from the surface)
16	To mill	1,13%	To separate
17	To keep	1,08%	To hold (in the certain place and time)
18	To bend	1,08%	To move (in certain direction)

So, the table above demonstrates that almost all functions which are statistically most often used can be substituted with the limited set of base/underlying functions.

It is important to point out the main difference between proposed approach of using four base types of functions and “Elementary Functions” Handbook. In fact, this approach is ready to be used in real projects as it is. Also, it can simplify introducing/explaining the function analysis to the 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 problem understanding as it's seen by the person/team (client) that owns the problem. Then, we need to create a function model by reformulating what the client knows using the set of base/underling functions. Of course, all parameters of each function including parameters of its object, subject and action should be taken into account.

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

4. Conclusions

The current research demonstrates that in order to understand how the system works and what its function disadvantages are, it is sufficient to use a limited set of base/underlined functions described in AFA format. The proposed approach is characterized with the following features:

- Simplified procedure and reduced time of the function analysis without compromising quality of its results;

- Easiness of introducing/explaining the function analysis to the people who are not familiar with this most important analytical tool of the Modern TRIZ.

The next steps are to investigate applicability of the proposed approach for increasing effectiveness and simplifying Function Oriented Search (FOS). Since the most general functions are already used for describing the system under analysis and parameters of those functions are also taken into account, it may be easier to perform search in the leading areas.

References

1. V.M Gerasimov., S.S. Litvin, “Basic statements of methodology for performing function-cost analysis: Methodological recommendations”- Moscow: Inform-FSA, 1991 (in Russian).

2. Simon Litvin, Naum Feygenson, Oleg Feygenson. Advanced Function Approach. Proceedings of the 10th ETRIA World TRIZ Future Conference 2010 – 3-5 November, Bergamo-Italy. pp. 79-85.

3. Hirtz J.M., Stone R. B., et al “A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts”. Research in Engineering Design, 2002; 13(2), pp. 65–82..

4. Kynin A., Priven A. Formulation of functions of an engineering systems with the matrix of generalized parameters // Proceedings of International Conference “TRIZfest-2013”, Kiev, Ukraine, August 1-3, 2013. – MATRIZ, St. Petersburg Polytechnic University publishing house, 2013, p. 59-67.

5. Fedosov Yu. Statistics of “Elementary Functions”; // Proceedings of International Conference “TRIZfest-2013”, Kiev, Ukraine, August 1-3, 2013. – MATRIZ, St. Petersburg Polytechnic University publishing house, 2013, p. 59-67.

Author (co-author) to contact: Oleg Feygenson, oleg.feygenson@gmail.com

TRIZfest 2014

Nuances of Hybridization of Alternative Systems: Transfer of the Features of "Impossible" Alternative Systems. (Case Study is based on OLED Display Manufacturing Problem described in USA Patent US 8461058)

MinSoo Kim[a], Valeriy Prushinskiy[b]

[a]*Samsung Display Company Ltd.,Yongin-City ,446-711, Republic of Korea*

[b]*Samsung Display Company Ltd.,Yongin-City ,446-711, Republic of Korea*

Abstract

Feature Transfer is an analytical tool for improvement of base engineering system by transferring relevant features from the alternative system. The approach was described and popularized by Vladimir Gerasimov and Simon Litvin at the end of 1980-s. Their initial algorithm of Feature Transfer is well known for generations of TRIZ-practitioners and produces robust results. At the end of 1990-s – beginning 2000-s Vladimir Gerasimov developed more comprehensive versions of the Algorithm of Hybridization of Alternative Systems, where he proposed idea of using "impossible" system as alternative, when "real" alternative system is not available or not capable to provide satisfactory results. In this case practitioners may use "impossible" system for Feature Transfer and improvement of engineering system. Nuances of this approach are demonstrated by authors in improvement of manufacturing process of OLED displays and. Proposed concepts are described in USA Patent US 8461058.

Keywords: Algorithm of Hybridization of Alternative Systems, Impossible Alternative Systems, OLED

1. Introduction

An alternative system is an object with the same main function as the base object. However, the advantages and deficiencies of the two systems are mutually opposite. Depending of the situation, alternative system can be selected by using one of the following recommendations [1]:

- Select only one of the existing competing systems
- Select one of the several existing competing systems
- Combine several existing competing systems
- Propose a hypothetical system - not existing, yet possible in principle
- Propose an impossible system, which violates the laws of physics

2. Algorithm of Hybridization of Alternative Systems

Selection of “impossible” alternative system is considered below as basis for concept development of US 8461058 according to the steps of the Algorithm of Hybridization of Alternative Systems, as it described in [1].

Step 1. Initial Situation

Organic layer deposition system includes electrostatic chuck with glass (500), evaporation source (110) for discharging a deposition material toward the glass and patterning mask (150), having plurality of patterning slits (151). Source (110), nozzle (121) and mask (150) are separated from the glass by a set distance, so as to perform deposition while the substrate is moved (fig. 1).

Main function of the system A is deposition of the organic material (placement of the layer of the material on the substrate into the openings of the mask).

The advantage of the system A is deposition of the organic material along the total width of the substrate.

The deficiency of the system A is that layers of deposited organic material have different width of lines and pattern shift (PS) on the left and right sides and in the central part of the substrate.

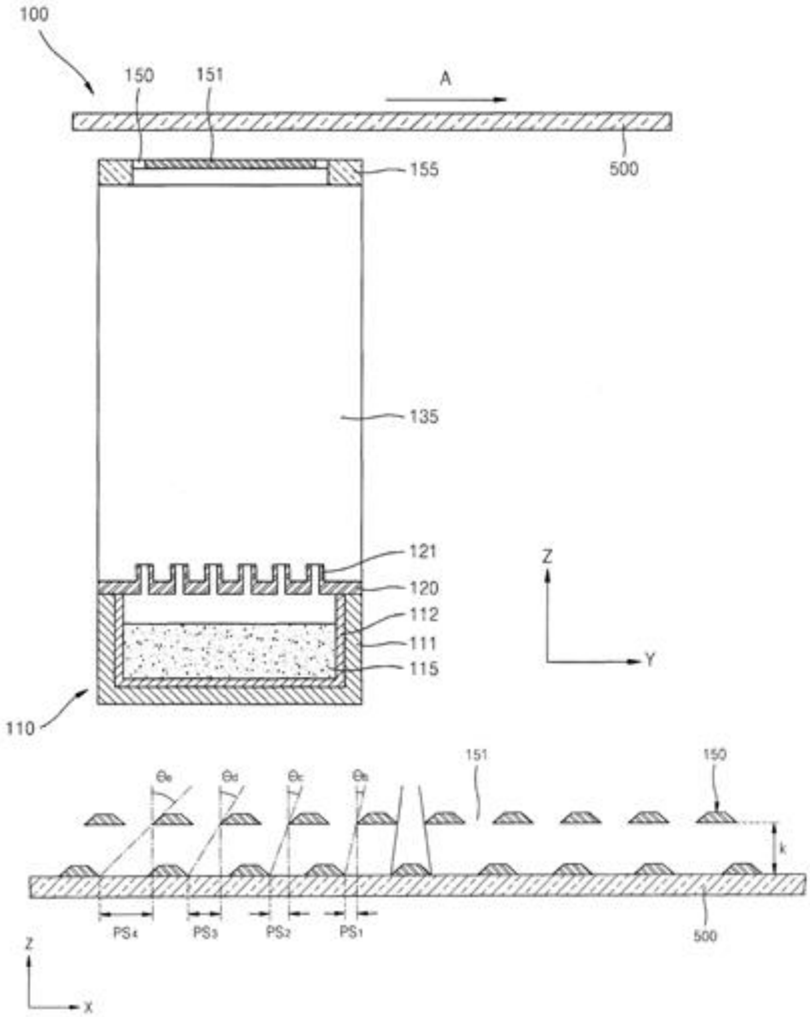


Fig. 1. Initial Situation

Step 2. Alternative System

After several attempts, due to the absence of real alternatives, hypothetical (impossible in framework of the initial concept) system was proposed as alternative system.

Main function of this imaginary System B is to deposit layers of organic material on the substrate.

The imaginary device can have a mask and substrate that bent around the source of the material, so that the layers of the material can be deposited in the right side, left side and the center of the substrate with the same width of the layer (fig. 2). Also this is advantage of the imaginary system, major disadvantage is that it is impossible to bend the glass as it is depicted on the figure 2, because the glass would be broken.

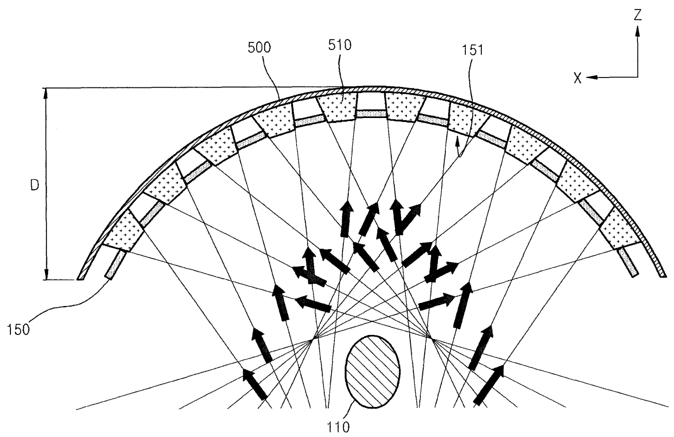


Fig. 2. Alternative System

Step 3. Alternative Contradiction

If we select the “System A” system, then

< *deposition of the organic material along the total width of the flat substrate* > - is good,

< *layers of deposited organic material have different width of lines on the left and right sides and in the central part of the substrate* > - is bad.

If we select “System B”, then

< *layers of deposited organic material have equal width of lines on the left and right sides and in the central part of the substrate* > - is good,

< *necessity to have bent substrate in order to have uniform deposition along the surface of the substrate* > - is bad.

Our new product has to be a System A, in order to have <*deposition of the organic material along the total width of the flat substrate* > as product A, and our new product has to be as System B, in order to have < *layers of deposited organic material with equal width of lines on the left and right sides and in the central part of the substrate* > as product B.

That is to say, our new hybrid concept has to be both a System A and a System B.

Step 4. Basic System Selection

As a rule, we should choose the simpler and less expensive system with inferior functional capabilities;

- if the systems we compare do not significantly differ in cost, but differ in functionality, we should extend our analysis with both of the systems taking turns as base system.

Because System A is simple and it was selected for installation, we select it as a basic system.

Step 5. Operative Zone of Basic System

Point to the area of the basic system where it is necessary to improve functionality.

Zone between the mask and substrate on the left side and on the right side of the device.

Step 6. Deficiencies of Basic System

Explain what is meant by “improve functionality”.

The new system has to keep the ability to deposit organic material along the full width of the basic substrate, and has to obtain the ability to deposit exact and uniform layers of the organic material without mixing them together.

Step 7. Problem

Formulate according to the rules of mini-problem statement:

“nothing has changed, yet the deficiency is eliminated”

“Nothing has changed, but the system A obtained the ability to deposit layers of material with same width in the middle of the plate and on the sides of the basic substrate”

Step 8. Resources of Alternative System

Bent surfaces of the mask and substrate provide the ability to deposit layers with uniform width.

In our case, we imagined bent glass substrate, impossible in real live, because it will be broken.

New concept: The substrate has to be straight in central part and it has to be bent in the left and right parts of the substrate.

Step 9. Composite Portrait of Solution

The System A remains the same as now – substrate with single source deposition of the layers, providing the ability to place uniform layers of material, but also obtain the ability to incorporate bent substrate and mask into its structure.

Step 10. Technical Solution

a. Partially bent substrate

Existing glass substrate is flexible enough to withstand slight bending and deposition of the material in this state.

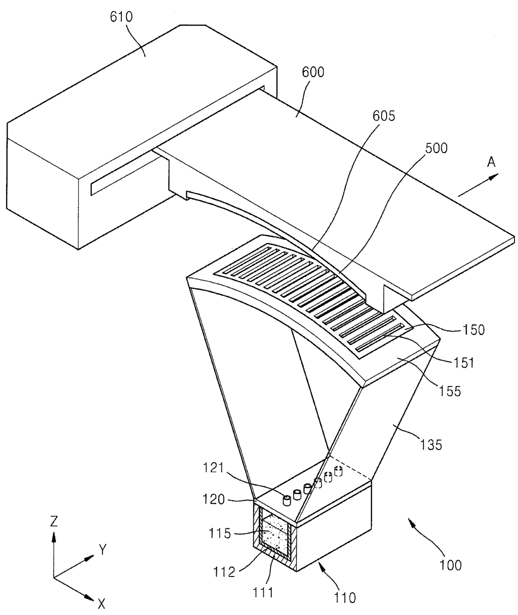


Fig. 3. Technical Solution

b. Flexible substrate

If it is possible to replace the glass substrate with the flexible glass or polymer material the substrate can be bent during deposition stage. Also, if we use bent mask, we can keep same basic principle (fixed mask, single source plus moving substrate) and have uniform deposition of the layers of the organic material.

Fig. 3. Flexible substrate

3. Conclusion and future trends

As has been discussed, the mask manufacturing process improved significantly through systematic innovations by applying hybridization using advantages of impossible alternative engineering systems in thinking process. Following steps can be recommended for defining "impossible" alternative:

- Define primary function of the engineering system
- Select components, carrying our main functions

- For selected components, think of parameters that impossible (e.g. leading to stop, breakage or collapse of the technological process as it is now)
- Imagine engineering system, which operates with components with “impossible” parameters
- Use this system as missed alternative for algorithm of hybridization of alternative systems and transfer features of “impossible” system onto the real basic system.

For tough cases, were there are no alternatives of engineering system or process, proposed thinking approach can provide a basis for generation of promising solutions and better innovative concepts.

References

1. HYBRIDIZATION, The New Warfare in the Battle for the Market, by Val Prushinskiy, Gafur Zainiev, Vladimir Gerasimov. ISBN 1-59872-069-4

2. USA Patent US 8461058

3. http://www.corning.com/news_center/features/willow_samples.aspx 5/10/2014

Author (co-author) to contact: Valeriy Prushinskiy, p.valeriy@samsung.com

TRIZfest 2014

Occasion Axis and Parameter-Function Pair Nexus for Effective Building of Cause Effect Chains

Hongyul Yoon

TRIZ Center, Seoul, 120-771, South Korea

Abstract

'Target Disadvantages' are the disadvantages which must be prevented to achieve the goal of an engineering project. In order to prevent Target Disadvantages, different approaches as Cause Effect Analysis have been suggested. Among them, the approaches based on building Cause Effect Chains have two important merits, compared with the others. First, Cause Effect Chains expose systematically root causes which appear as the first causes of Cause Effect Chains. Because elimination of root causes is the most effective, the systematic disclosure of root causes helps solvers to prevent finally Target Disadvantages. However, this merit requires examination of the whole relations among many causes of Target Disadvantage which is substantially determined by preliminary overall understanding of the initial problem situation. Secondly, Cause Effect Chains provide not only high possibility to treat root causes but also a lot of alternatives to prevent Target Disadvantages by 'cutting the chains of causes'. The elimination of root causes is not always possible, which is often due to limitation of resource change in real situations. As for those cases, we must cut the Cause Effect Chains by prevention of certain causes which locate between root causes and Target Disadvantages to compose Cause Effect Chains. The possibility of cutting Cause Effect Chains depends strongly on completeness of Cause Effect Chains. The more causes we find, the bigger possibility we have to cut the Cause Effect Chains related to Target Disadvantages.

In this paper, from the above viewpoints, the author will introduce novel methods which are named 'Occasion Axis' to get effectively the overall understanding of the initial problem situation in order to perform examination of causal relations and 'Parameter-Function Pair Nexus' to achieve the bigger completeness of Cause Effect Chains. The main notions of 'Occasion Axis' and 'Parameter-Function Pair Nexus' will be explained with detailed steps of application and real cases. Both methods have been successfully used for some leading corporations worldwide including Samsung, LG, POSCO, Hyundai, and Amore Pacific, etc. since 2005.

Keywords: Cause Effect Chain Analysis, Occasion Axis, Parameter-Function Pair Nexus.

1. Introduction

Cause Effect Analysis is one of the most important tools for analysis of a problem situation and identification of key problems not only related to engineering problem solving[1-8] but also related to TRIZ application. Especially in TRIZ field, 'Target Disadvantages' are the disadvantages which must be prevented to achieve the goal of an engineering project. In order to prevent Target Disadvantages, different approaches as Cause Effect Analysis have been suggested. Previous methodological studies have been done like AFD of B.Zlotin and A.Zusman, Cause Effect Chain Analysis of GEN3, Root Conflict Analysis of V.Souchkov, Why-Why Analysis of A.Pinyaev and others[9-17]. Among them, the approaches based on building Cause Effect Chains have at least two important merits. First, Cause Effect Chains expose systematically root causes which appear as the first causes of Cause Effect Chains. Because elimination of root causes is the most effective, the systematic disclosure of root causes helps solvers to prevent finally Target Disadvantages. Secondly, Cause Effect Chains provide not only high possibility to treat root causes but also a lot of alternatives to prevent Target Disadvantages by 'cutting the chains of causes'. The elimination of root causes is not always possible, which is often due to limitation of resource change in real situations. Even as for those cases, we can prevent Target Disadvantages by cutting the Cause Effect Chains by prevention of certain causes which locate between root causes and Target Disadvantages to compose Cause Effect Chains. This latter merit gives the problem solvers very practical advantage.

However, the current Cause Effect Chain Analysis has some demerits. Most of all, the result of building Cause Effect Chains is not consistent among different analysts while other popular TRIZ tools like Function Analysis seem to result in similar results irrespective of who performs the analysis. In order to get 'consistency' of the result, the author believes that Cause Effect Chain Analysis requires examination of the whole relations among many causes of Target Disadvantage which is substantially determined by preliminary overall understanding of the initial problem situation. From this viewpoint, the author introduced a novel way, 'Occasion Axis' to get effectively the overall understanding of the initial problem situation in order to grasp the causal relations among all of resources. Secondly, the possibility of cutting Cause Effect Chains depends strongly on completeness of Cause Effect Chains. The more causes we find, the bigger possibility we have of cutting the Cause Effect Chains related to Target Disadvantages. The fact requires us the ways to find 'missing causes' from the draft of Cause Effect Chains. About this points, this paper will present a novel method, 'Parameter-Function Pair Nexus' to achieve the bigger completeness of Cause Effect Chains, which is unique and different from the previous suggestions like what A.Pinyaev offered in his Why-Why Analysis.

2. 'Occasion Axis' for grasping the causal relations among all of resources

The premise of 'Occasion Axis' is that a certain event in physical world happens under a specific condition and the specific condition is determined by values of particular parameters of something related to the event, NOT just along the Time Axis.

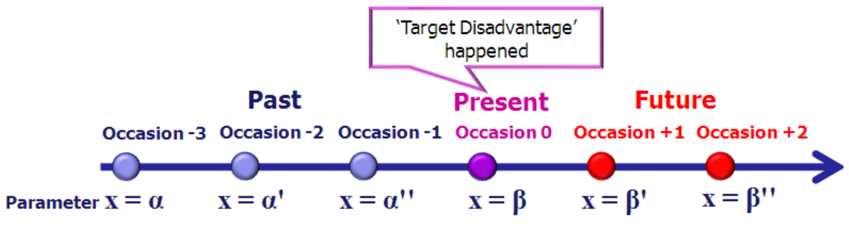


Fig. 1. A schematic explanation about the deployment of 'Occasion Axis'

2.1. Definition of 'Occasion Axis'

'Occasion Axis' is the series of certain times according to the variation of a certain parameter value of something shown in Fig. 1. In the name of 'Occasion Axis', the word 'Occasion' means a time when a particular parameter of something in our problem situation has a certain value. The author developed 'Occasion Axis' from a notion that a certain time stage of Multi

Screen Thinking should be determined not only along a time flow but also along conditions with the parameter value change of resources. Very often, we have to think about super/subsystems according to certain occasions which are determined by the change of parameter value of certain resources instead of a simple time flow. Therefore, we should check the values of parameters of some resources. The main two kinds of parameters to determine conditions are the evaluation parameters expressed in the target disadvantage and the control parameters of certain resources.

2.2. Deployment of 'Occasion Axis' for building Cause Effect Chains

'Occasion Axis' is based on the question, "what times and what conditions are related to causes of the target disadvantage?"[18]. At each Occasion along 'Occasion Axis, we can find causes of the target disadvantage. 'Occasion Axis' is deployed typically through the following procedure.

(1) Identify the evaluation parameter out of the target disadvantage. The evaluation parameter means the parameter to evaluate the degree of the target disadvantage.

(2) Set the reference point, or 'present' with the value of the evaluation parameter of the target disadvantage. 'Past' includes 'Occasion' which is closer to 'no occurrence' of the target disadvantage. 'Future' is about 'Occasion' after the target disadvantage happens.

(3) Changing the value of the evaluation parameter over 'past' and 'future', check the plausible causes for the target disadvantage.

(4) If you know one or more parameters to control the target disadvantage, you should deploy 'Occasion Axis' at different values of the control parameters so that you examine more plausible causes.

The reason to examine the future 'Occasion' is that there might be causal relations like a vicious circle. Not always, but it is possible for the target disadvantage to happen as part of a vicious circle. Only if you find a cause in the future 'Occasion', there may be a vicious circle. As a vicious circle example to show the necessity of the future 'Occasion', a case to prevent rock splitting by water in natural conditions is explained as follows. Let us suppose that we are interested in water effect about the splitting of rocks exposed in natural condition. There is a split rock by water in natural conditions and this present situation is identified as 'the target disadvantage'. Set the reference point, or 'present' with the value of the evaluation parameter 'crack length' of the target disadvantage. In natural conditions, water and rocks are exposed to a lot of circumstance changes. Among the changes, the temperature change was chosen to be considered because everything in the universe might be influenced by heat transfer.

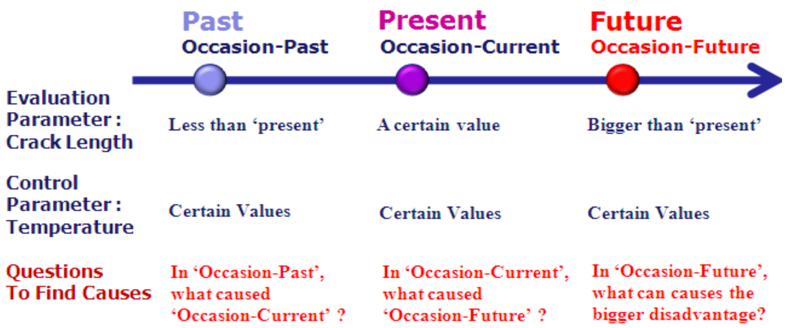


Fig. 2. An example of 'Occasion Axis' deployment about rock splitting by water in natural conditions

If there is no significant influence due to temperature change, another parameter change can be considered later. In this case, 'Occasion Axis' may be as shown in Fig.2. If we start examination from the condition of no crack in a rock, we can suppose any kind of impact on the rock to make a crack. Therefore, we can introduce one more 'Occasion-Past2' and 'Occasion-Past1' shown in Fig.3. After crack beginning, water gets into the small crack during 'temperature > 0℃'shown in 'Occasion-Current'. If temperature drops down to lower than 0℃, for example, 'at night in winter', water inside the crack freezes. During freezing, ice expands by about 9 %. This expansion results in the pushing stress on the crack and then the crack becomes a little bit bigger. If we go further like 'Occasion-Future' shown in Fig. 3, we can find the same phenomena as discussed previously. The repetition of water seeping and freezing makes the crack bigger and bigger.

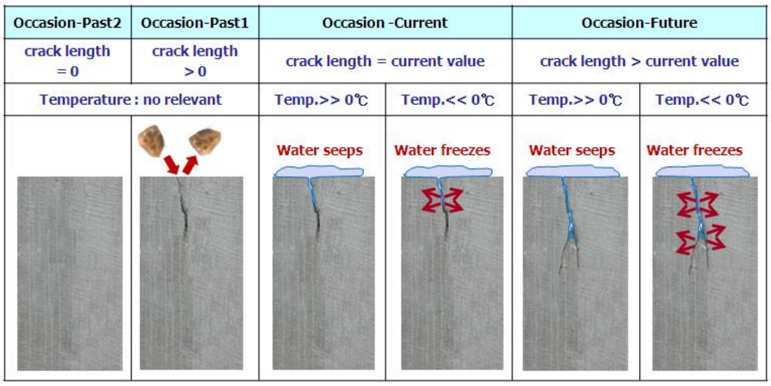


Fig. 3. An example of finding vicious circle through application of 'Occasion Axis'

Likewise, if we find any plausible cause at 'Parametric future of the target disadvantage', that means the causal relationship may be a vicious circle, or 'a circular cause effect relationship'. As for this example, the vicious circle continues until the rock is completely split into two pieces.

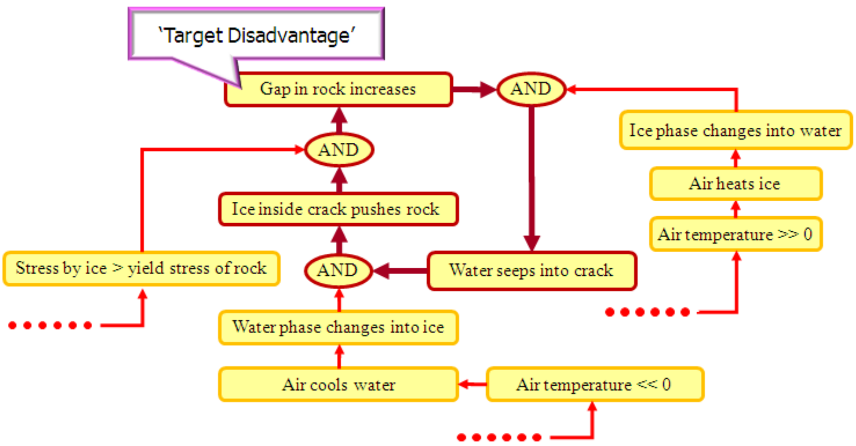


Fig.4. The vicious circle part of Cause Effect Chains about the example

Generally, we can start from the information at Occasion-Current. And then, we integrate the information with others at Occasion-Past. Any causes at 'Occasion-Future', or 'Parametric Future of the target disadvantage' lead us to build a vicious circle. The vicious circle part of the full Cause Effect Chains about the example case might be constructed shown in Fig.4.

2.3. Integration of 'Occasion Axis' and the other TRIZ tools

'Occasion Axis' can be used as 'Parametric Multi Screen Thinking' and that means it can be used with many other popular TRIZ tools. Especially, for more consistent and easier building Cause Effect Chains, 'Occasion Axis' can be applied with System Scale Axis(i.e., Hierarchy Axis) of Multi Screen Thinking, Function Analysis and Parameter Analysis. Fig. 5 shows roughly a schematic image of an example of integration of 'Occasion Axis', System Scale Axis and Function Analysis.

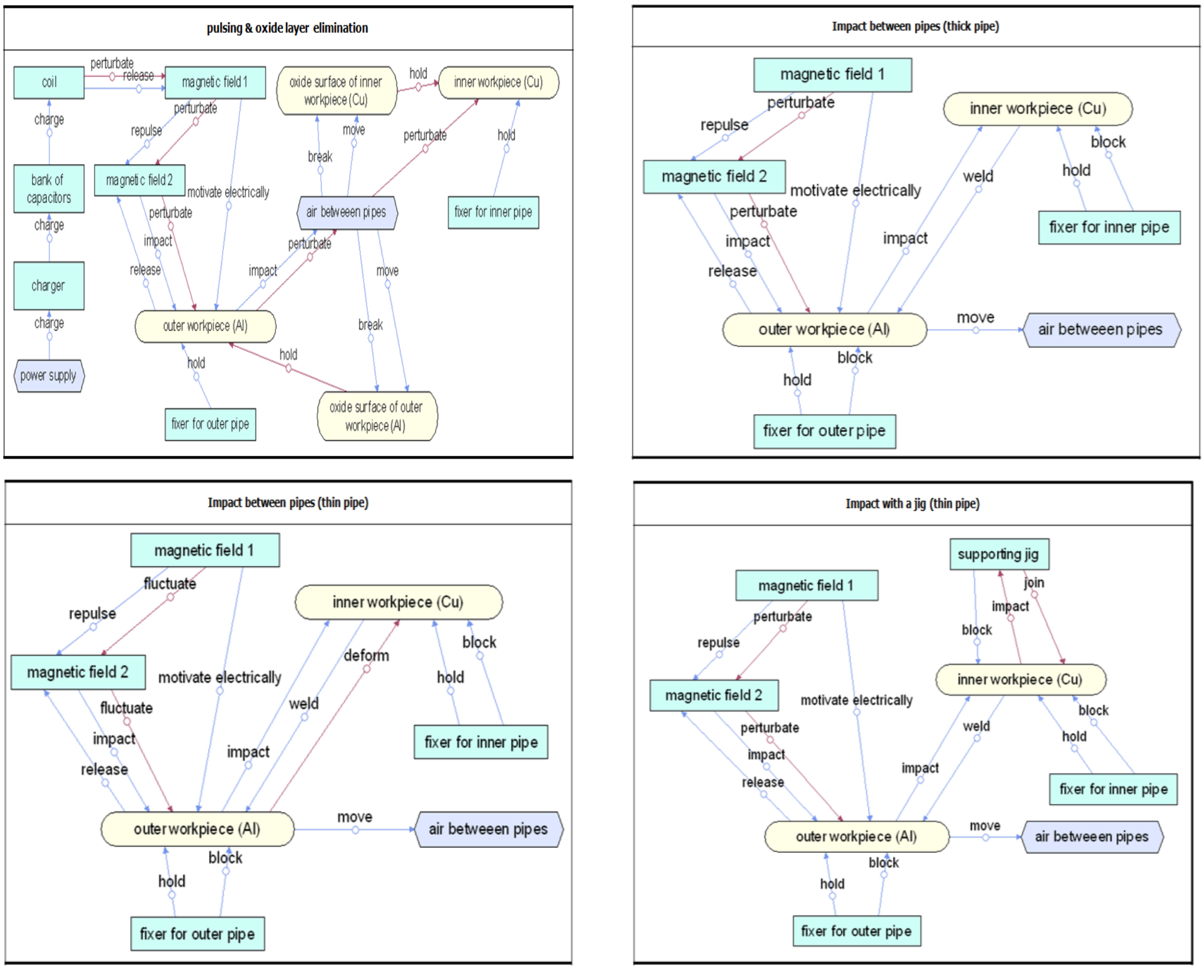


Fig. 5. A schematic image of an example of integration of 'Occasion Axis', System Scale Axis and Function Analysis

Let us go over a general procedure of 'Occasion Axis' application with System Scale Axis, Function Analysis and other TRIZ analytic tools in order to build Cause Effect Chains.

(1) Identify the evaluation parameter out of the target disadvantage. The evaluation parameter means the parameter to evaluate the degree of the target disadvantage.

(2) Set the reference point, or 'present' with the value of the evaluation parameter of the target disadvantage. 'Past' includes 'Occasion' which is closer to 'no occurrence' of the target disadvantage at the evaluation parameter = 0. 'Future' is about 'Occasion' after the target disadvantage happens.

(3) Analyze resources of each 'Occasion' according to System Scale Axis or/and Function Analysis, or/and other TRIZ analytic tools because every cause is from resources

related to the target disadvantage. Try to answer the question, “What resources could provide ‘all disadvantages’ of the system?”.

(4) Build Cause Effect Chains based on the result of the previous steps.

3. ‘Parameter-Function Pair Nexus’ for finding missing causes of Cause Effect Chains

Since 2005, the author introduced 'Parameter-Function Pair Nexus' to examine the completeness of Cause Effect Chains and find missing causes[19]. 'Parameter-Function Pair Nexus' is based on the hypothesis that, if we get a complete set of Cause Effect Chains about a physical phenomenon, ‘a causal state described by a certain parameter value of a certain entity’ follows ‘a causal interaction described by a certain function between entities’ and vice versa, ‘a causal interaction described by a certain function between entities’ follows ‘a causal state described by a certain parameter value of a certain entity’. Before we examine the definition of ‘Parameter-Function Pair Nexus’, let us think about some examples of the parameter description and the function description which are given in Fig. 6. It must be notified that only a parameter cannot be a description of a state. Every state is the state of a certain entity. Therefore, a certain state of an entity must be depicted by ‘entity + parameter of it + evaluation of the parameter’ like ‘water container’s temperature higher than 100℃’. On this basis, the description of a certain interaction between entities is given by ‘entity + function model (+ evaluation of the function)’ like ‘water container heats water in it (insufficiently)’. Based on the above discussion, the author introduced the definition of ‘Parameter-Function Pair Nexus’ like the following section explains.

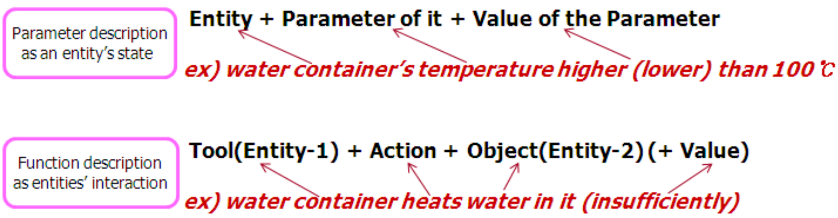


Fig. 6. examples of how to describe a state of an entity and an interaction of entities

3.1. Definition of ‘Parameter-Function Pair Nexus’

‘Parameter-Function Pair Nexus’ is a nexus composed of pairs of ‘parameter value description’ as a state of a thing and ‘function description’ as an interaction between things. (Fig. 7 explains ‘Parameter-Function Pair’ in a Cause Effect Chain.)

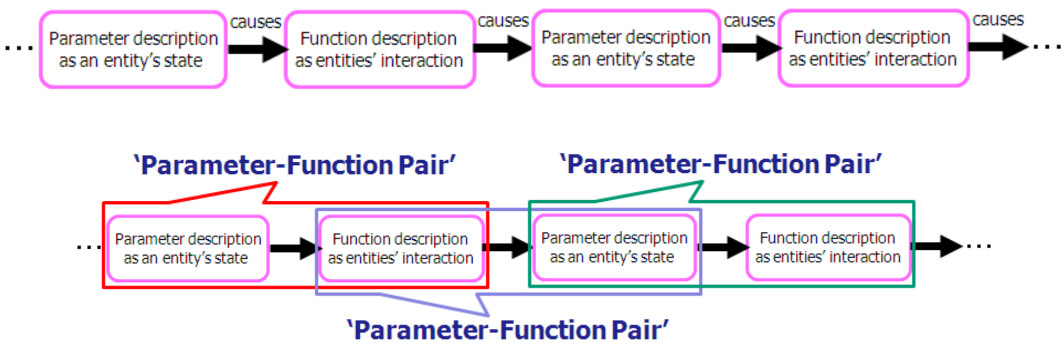


Fig. 7. ‘Parameter-Function Pair’ in a Cause Effect Chain

The premise of ‘Parameter-Function Pair Nexus’ is that in physical world, interactions among entities happen only if certain state conditions are reached among them and certain states among entities are achieved only by certain interactions. Only states cannot result in different states. Through interactions, a certain state causes another state. As for interactions, any interaction cannot directly result in another interaction without fulfillment of a certain state condition.

If the rule of description is kept strictly, 'Parameter-Function Pair Nexus' also helps us to find which resource must be examined to identify causes or find missing causes shown in Fig. 8.

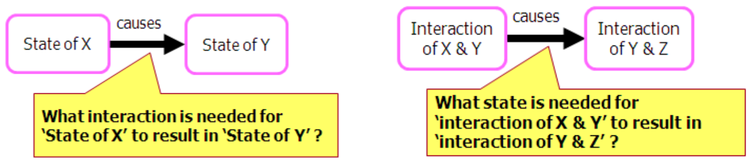


Fig. 8. Sample questions based on ‘Parameter-Function Pair Nexus’ for finding missing causes in Cause Effect Chains

Based on the explained reasoning, the author suggests the following ways to find hidden causes with ʻParameter-Function Pair Nexusʹ.

Case-1: Finding hidden causes by revising the forms of description of causes
Case-2: Finding hidden causes by checking if the interaction is ‘Direct Interaction’.
Case-3: Finding hidden causes by introducing missing interactions or states

3.2. Use of ‘Parameter-Function Pair Nexus’

From now on, the above three cases will be explained in detail. Let us suppose that we have just finished the first version of Cause Effect Chains.

First of all, we examine the case of ‘insufficient description’.

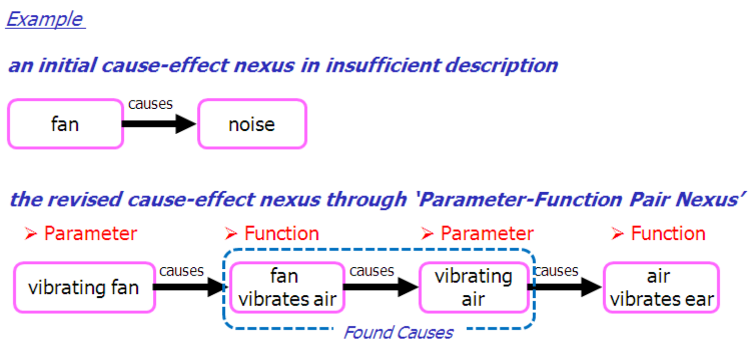


Fig. 9. Application of 'Parameter-Function Pair Nexus ' to insufficient descriptions of causes

Check if 'Parametric State' description is expressed in the form of 'entity + a certain parameter of it + value of the parameter' and 'Functional Interaction' description is expressed in the form of 'Tool + Action + Object'. If not, first of all, the description must be changed according to the requirements. Through correction, we might find missing hidden causes. For example, let us suppose a pair of Cause-Effect is described as only nouns, ‘fan’ and ‘noise’ like shown in Fig. 9. According to 'Parameter-Function Pair Nexus ', we have to identify at least two causes related to ‘fan’ and ‘noise’, one is the state of the fan as a cause and another is the cause as the interaction between the fan and other resources.

Next, let us examine the case of identification of ‘Direct Interactions’. ‘Direct Interaction’ means there is no intermediate transmitter to deliver the interaction between the entities. If the nexus of one cause and one result is a pair of 'Function' description as a interaction and 'Parameter' description as a state shown in Fig. 10, check if the 'Interaction' is being done DIRECTLY between 'Entity' of 'State' description and another 'Entity' as 'Tool' or 'Object' of the 'Interaction' description. If the 'Function' is 'NOT' being done directly between 'Entities', that means there should be some 'hidden causes' between the initial two causes. Go back to ‘Occasion Axis’ application with System Scale Axis and find 'Entities' which directly interact with each other between the initial Cause event and Effect event. Through this procedure, we might find some hidden causes.

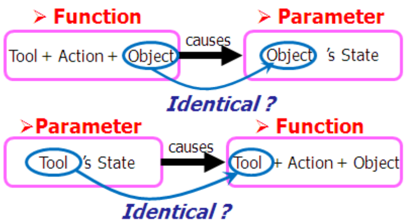


Fig. 10. ‘Direct Interaction’ checking ways about typical causal relations

If the nexus of one cause and one result is 'NOT' a pair of 'Parametric State' description and 'Functional Interaction' description, there might be several different cases. First of all, let us consider an initial pair of ' Parametric State' descriptions like the case shown in Fig. 11.

Fig. 11. The case of a pair of 'Parametric State' descriptions

If we have an initial causal nexus which involves only ‘Parametric State’ descriptions, we have to find what kind of interaction happens between two objects appeared in the initial Cause Effect nexus. The missing interaction should be the hidden cause. It is a matter of course that we should also check ‘Direct Interactions’ after doing this way to find missing causes. For example, let us consider a pair of 'Parametric State' descriptions about ‘ice melting disadvantage’ drawn in Fig. 11. According to ‘Parameter-Function Pair Nexus’ and ‘Direct Interaction’, we have to check what kind of ‘Functional Interaction’ happens between ‘Surrounding air’s temperature>40℃’ and ‘Ice’ melting rate > acceptable value’. That leads us the missing cause, ‘Air heats ice’.

Let us think about an initial causal link which involves only ‘Functional Interaction’ descriptions shown in Fig. 12.

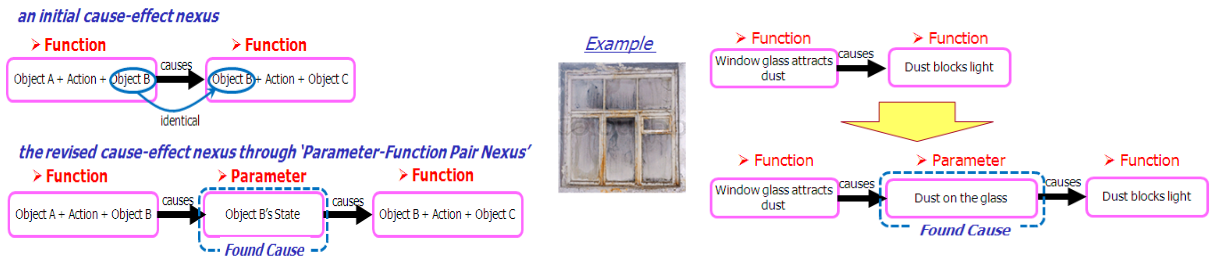


Fig. 12. The case of a pair of 'Direct Interaction' descriptions

As for this case, we have to find what state of ‘Object B’ is required for the former interaction to result in the following interaction appeared in the initial Cause Effect nexus. The missing state of ‘Object B’ should be the hidden cause. An example is give as a pair of 'Functional Interaction' descriptions about ‘a dark room of dusty windows’ explained in Fig. 12. According to ‘Parameter-Function Pair Nexus’ and ‘Direct Interaction’, ‘dust’ must be a certain ‘Parametric State’ caused by the ‘Functional Interaction’, or ‘window glass attract’. We have to examine the real situation to find the condition of ‘dust’. That leads us to the hidden cause, ‘Dust on the glass’.

Next, we will think about an initial pair of ‘Indirect Interaction’ descriptions like the case shown in Fig. 13. Concerning this case, we have to find several missing ‘Parametric States’ and ‘Direct Functional Interactions’ of ‘Object B’, ‘Object C’ and if any, other intermediate entities between them. This case usually requires some repetition of application of ‘Parameter-Function Pair Nexus’ explained previously. For example, let us consider ‘oxidization of hot steel cords during fabrication’ shown in Fig. 13. The oxidization is usually accepted at the final stage of steel cord fabrication but it is NOT allowed to have too thick oxidized layer on the surface of the steel cord. So, the cooling air is adopted to control the thickness of oxidized surface layer. If we have a pair of INDIRECT ‘Functional Interaction’ like ‘fan moves air insufficiently’ and ‘steel combines with O_2 fast’, some repeated application of ‘Parameter-Function Pair Nexus’ according to the previous explanations leads us the hidden causes shown in the lower part of Fig. 13.

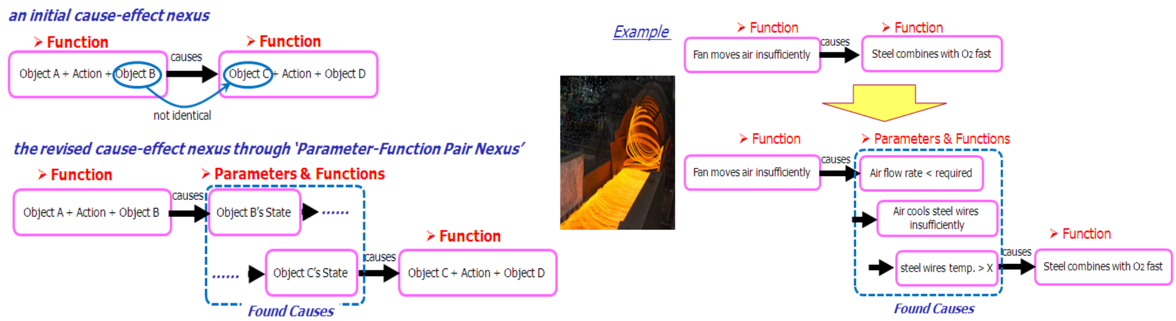


Fig. 13. The case of a pair of 'Indirect Interaction' descriptions

4. Conclusions

(1) A new analytic method is suggested for easier and more consistent building Cause Effect Chains, 'Occasion Axis'. It deploy several occasions according to changes of evaluation parameters and control parameters. The analysis on the problem situation along ‘Occasion Axis’ and System Scale Axis can give us an overall comprehension. ‘Occasion Axis’ can be easily and efficiently integrated with Parameter Analysis and Function Analysis which

deploys interactions among resources and conditions of them that are necessary information of building Cause Effect Chains.

(2) An absolutely new guide for building more complete cause-effect chains is introduced. It is called the 'Parameter-Function Pair Nexus' which is composed of alternating pair series of a 'Parametric State' like 'entity + parameter of it +evaluation of the parameter' and a 'Functional Interaction' like 'entity + function model + evaluation of the function'. Checking Cause Effect Chains according to 'Parameter-Function Pair Nexus' leads us to find missing causes.

The developed methods have been very successfully used in various projects for different leading corporations worldwide since 2005, especially for Samsung Electronics, Samsung SDI, Samsung Mobile Display, LG Display, POSCO, Hyundai Motors, Hyundai Mobis, and Amore Pacific, etc.[20-22].

References

1. R.Keith Mobley, Root Cause Failure Analysis, Newnes, 1999
2. A.A. Hattangadi, Plant and Machinery Failure Prevention, McGraw-Hill, 2005
3. Neville W. Sachs, Practical Plant Failure Analysis, CRC Press, 2007
4. Anthony Mark Doggett, Root Cause Analysis, American Society for Quality, 2005
5. Bjørn Andersen, Tom Fagerhaug, Root Cause Analysis, American Society for Quality, 2006
6. Anthony Mark Doggett, "A Statistical Comparison of Three Root Cause Analysis Tools", Vol.20, Journal of Industrial Technology, The National Association of Industrial Technology, 2004
7. G. Medina Oliva, B. Iung, L. Barbera, P. Viveros, T. Ruin, "Root Cause Analysis to Identify Physical Causes", ESREL, 2012.
8. http://www.marshallinstitute.com/inc/eng/MT/Areas/seminars/body/brochures/MI/rca_general.pdf visited 07.06.2013
9. Ideation International Inc., material for workshops about Ideation Methodology, USA, 2001.
10. Ideation International Inc., Anticipatory Failure Determination, USA, 2004.
11. Stan Kaplan, Svetlana Visnepolschi, Boris Zlotin and Alla Zusman, New Tools for Failure and Risk Analysis, Ideation International Inc., 1999, 2005.
12. Valeri Souchkov, Root Conflict Analysis (RCA+): Structured Problems and Contradictions Mapping, White paper, 2004.
13. Sergei Ikovenko, material for MATRIZ level 1 certification course, Korea, 2008.
14. Serge Pesetsky, Haibo Duan, Minyi Zhang, "Innovations Through Enhanced RCA, Ontological Search and TRIZ Based Reasoning", Proceedings of the ETRIA TRIZ Future Conference, Florence, Italy, 2004.
15. Leonid Batchilo, Alp Lin, Hyman Duan, "Combining Cause-Effect Analysis and TRIZ Nine Screens", Proceedings of the ETRIA TRIZ Future Conference, Graz, Austria, 2005.
16. IWINT, Inc., Pro/Innovator Training Guide, 2005.
17. Aleksey Pinyayev, A Method for Inventive Problem Analysis and Solution Based On Why-Why Analysis and Functional Clues, TRIZ Master dissertation, 2007.
18. Hongyul Yoon, " 'Occasion Axis' to select the proper TRIZ thinking tools through investigation of the initial problem situation", Global TRIZ Conference, Seoul, 2013
19. Hongyul Yoon, Training material of TRIZ, Seoul, 2005~2012.
20. Siyoung Cho, Taeryong Lee, Daegun Kim, Byungfhy Suh, Hongyul Yoon, "Case Study of ARIZ-85C Application to Isolation of the Binding of Target Proteins", TRIZ Journal, 2008

21. Hongyul Yoon, "OSTM-TRIZ Guide to Increase Effectiveness of Root Conflict Analysis", The 6th TRIZ Symposium in Japan, Atsugi-shi, Japan, 2010.
22. Byung-Sub Park, Bong-Kyoung Park, Hongyul Yoon, "Samsung SDI's Innovation through TRIZ:A Case Study on Cost Reduction", Global TRIZ Conference, Seoul, 2012

Author (co-author) to contact: Hongyul Yoon, hongyul@trizcenter.co.kr

TRIZfest 2014

On developing ARIZ-Universal-2014

Michael Rubin

St. Petersburg, 191119, Russia

Abstract

A new version of universal algorithm for inventive problem solving (ARIZ-U-2014) applicable both to engineering and non-engineering fields is proposed. A problem model in ARIZ-U-2014 is based on a set of models for functions (useful, insufficient and harmful). Such an approach automates the process of formulating requirement contradictions, IFR, selecting standards for inventive problem solving and formulating other ARIZ steps. The software complex COMPINO-TRIZ is presently being created based on ARIZ-U-2014.

Keywords: ARIZ, function of a system, contradictions of requirements, inventive problems outside engineering, Element-Field (Ele-Field) analysis, Systems evolution science.

1. Problem Statement

Since the first publications of G.S.Altshuller and R.B.Shapiro in 1956, the algorithm of inventive problem solving in its different modifications remains the main TRIZ tool. The ongoing development of ARIZ takes into account the results of new research in TRIZ as well as new tasks set before TRIZ. In particular, this research is described in publications [2-6]. The Universal Algorithm for Inventive Problem Solving-2014 (ARIZ-U-2014) offered for consideration here is based on the previous version of this algorithm ARIZ-U-2010 [8].

The main difference of ARIZ-U-2010 from its previous versions is that it can be applied not only to engineering systems, but also to non-engineering (e.g., biological) and even non-material ones (informational, legal, scientific and other). ARIZ-U-2010 steps include system analysis, synthesis of a new system, and evaluation and revision of proposed ideas.

ARIZ-U-2014 is intended to enhance the formalization of performed steps to the degree that enables their implementation by means of computer software. Most of algorithm steps (including recommendations on inventive problem-solving standards) are executed in ARIZ-U-2014 automatically through the formulation of problems as a set of models of functions (useful, insufficient and harmful).

2. Notions and terms of ARIZ-U-2010 and ARIZ-U-2014

There are terms and notions, used in ARIZ-U-2010 and ARIZ-U-2014 that require preliminary refinement:

- Function model includes a Subject (carrier) of the function and an Action directed at the Object of the function. The action could be described by a verb or variations of one or more parameters of the function Object. The author has identified five options of action affecting a function object parameter: increase – decrease, stabilization – variation, measurement.

- Set of system functions: a set of function models (1-5 and more) interconnected by elements and containing conflicting requirements.

- FOS – Function-oriented search is intended for revealing systems with analogous functions; the inverse FOS is a search for possible fields of application for a function.

- Function-field analysis is the analysis of a function model of a system, augmented with fields of interaction between function components. A function model of a system consists of models of functions. A function-field system consists of Element-Fields (Ele-Fields) of this system.

- Standard models (patterns) of conflicts are described in [2] and in Table 2.

- Ele-Field (elements and their fields of interaction) is a generalized analog of a Su-Field and function model for material and non-material systems. An Ele-field is a function model, supplemented with a field of interaction between function carrier and function object [7].

- Universal Standards System for Inventive Problem Solving 2010 [7] is designed to search for inventive problem solutions for material and non-material systems.

- Contradictions of requirements represent a generalized analog of an engineering contradiction for material and non-material systems. The requirements to system come from the supersystem. Formulation: IF...(indicate the change to be introduced), THEN (+indicate the main requirement), BUT (indicate the non-desirable requirement).

- Contradictions of features represent a generalized analog of a physical contradiction for material and non-material elements. It can be formulated for any features (aspects of analysis) of objects: physical, chemical, biological, aesthetic, artistic, etc. The features of a system are associated with its internal structure. Formulation: an element of a conflicting pair must possess feature X to meet the main requirement, and must possess feature "ANTI-X" to eliminate a harmful function associated with it.

- Aspects of system analysis: physical, chemical, biological, engineering, social, psychological, legal, financial-and-economic, etc.

- Principles for resolving feature contradictions: in time, in space, through system transition, in relationships. Resolving of relationship contradictions can be used both for material and non-material systems.

- Techniques for resolving requirement contradictions (40 major and additional techniques proposed by G.S.Altshuller [2] for engineering problems). A separate set of techniques for resolving requirements contradictions can be related to one contradictions resolving principle. Some the principles (25 out of 40 major one [11]), e.g., fragmentation, taking out, integration, vice versa, dynamicity, etc., can be applied to non-material systems.

- Functional IFR: An object (indicate) does (describe) by ITSELF during the period (indicate, what period) under mandatory conditions (describe the constraints).

- Resource IFR: X-element from system resources ELIMINATES by ITSELF harmful functions (indicate), while RETAINING useful functions (indicate).

- Feature IFR: The operational zone (indicate) during the operational time (indicate) must provide for (indicate the opposite macro- or micro-states or features) by ITSELF.

- SFR means substance-and-field resources as well as other resources.
- The principle of system operation is determined by three parts: system components, system of functions, and system "tissue" (what system components consist of).

3. Block-diagram of ARIZ-U-2014

Fig. 1 shows the ARIZ-U-2014 block diagram.

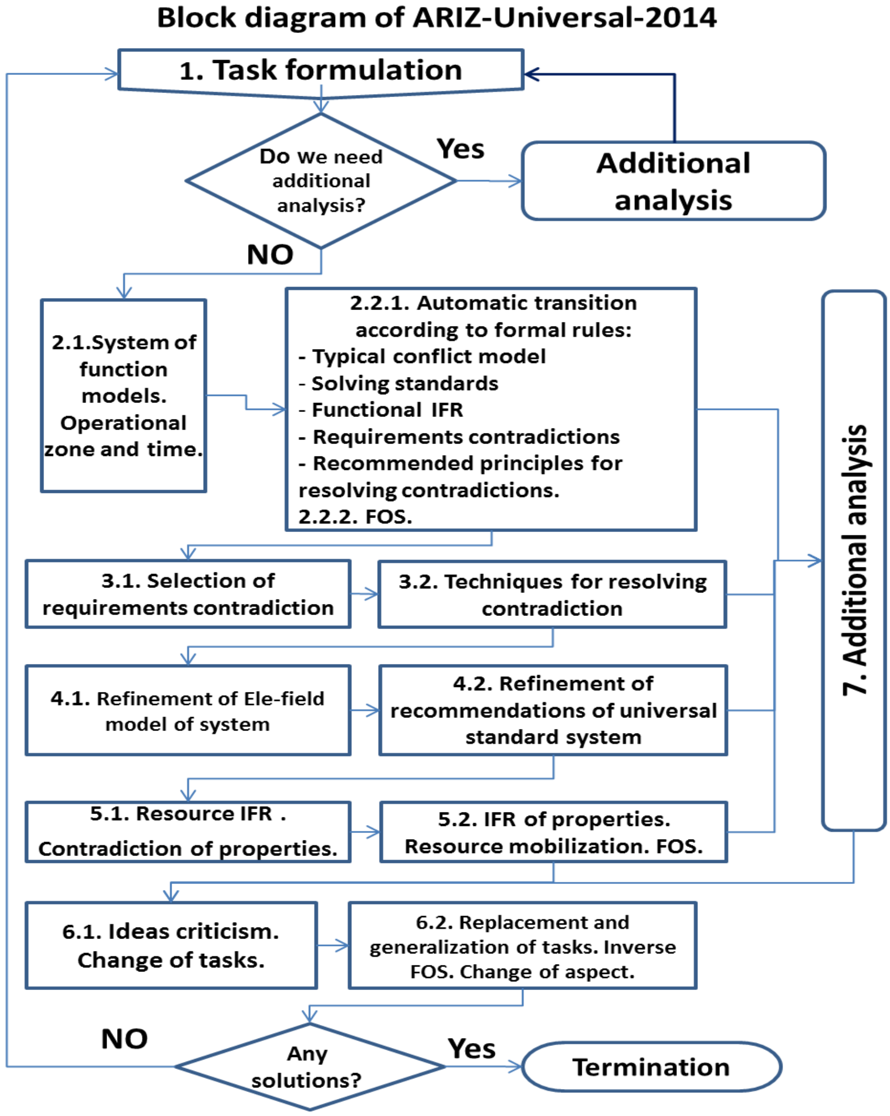


Fig. 1. Block diagram of ARIZ-U-2014.

All steps of ARIZ-U-2014 are divided into three groups: system analysis, synthesis of a new system, and evaluation and criticism of proposed ideas. (Fig. 2).

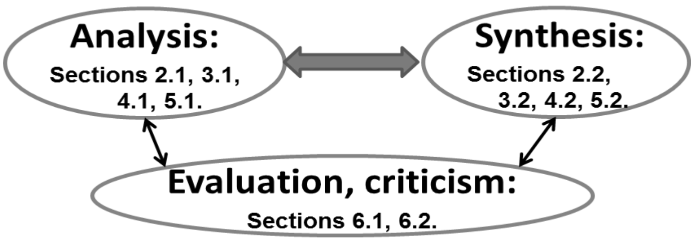


Fig. 2. Logics and interrelation of individual sections of ARIZ-U-2014.

Step 2.2.1 is performed based on formal rules described below and which are completely automated in the program COMPINO-TRIZ, which is described below. Table 1 offers a comparison between ARIZ-U-2010 and ARIZ-U-2014.

Table 1: Comparison of ARIZ-Universal-2010 and ARIZ-UNiversal-2014

Section	ARIZ-U-2010	ARIZ-U-2014
Com-ments	Analysis of systems: engineering, non-engineering, non-material (informational), statement and solving of inventive problems. For problems of Levels 2-4. Short description of ARIZ-U-2010 steps is given below.	Adapted for use in computer programs; problem model is stated as a system of functions, the main formulations are defined automatically. The changes listed below are introduced.
1	Source problem. System elements and parameters. Problem template. Problems re-formulation. System analysis, function-and-field analysis, etc. Use of different methods of analysis and problem statement (key problems identification, etc.). Problem scale analysis template. Must the stated problem be solved?	The template of problem formulation is transferred to step 2.1 and integrated with the template of function.
2.1.	The model of function and constraints. The template of function. Analysis of parameters and parametrical model of function. Information search in information bases. Operational time (OT). Operational zone (OZ).	Following the assigned template, a set of functions (numbering 1-3 or more) containing disadvantages and contradictions is described. Based on this functions system, the type of conflict is determined automatically, standards for conflict elimination are offered, statement of contradiction of requirements and functional IFR is proposed.
2.2.	Functional IFR. FOS. Information search. Function model refinement. Source problem refinement.	Selection of functional IFR statement proposed by the algorithm.
3.1.	Contradictions of requirements: CR-1, CR-2. Refinement of algorithm for formulating the contradictions of requirements.	Selection of requirements contradictions proposed by the algorithm.
3.2.	Table of techniques. Conflict resolution techniques.	Selection of techniques that are most suitable for the problem becomes possible.
4.1.	Conflicting elements. Conflict pattern. OT. OZ. Multi-variety of conflict models.	The automatically selected conflict model is refined if necessary.
4.2.	Ele-field model of the problem. System of standards.	Problem model and problem solving standards are refined if necessary.

Other sections of ARIZ-U-2014 remained unchanged as compared to ARIZ-U-2010:

5.1.	Resource-related IFR. Feature contradictions. Resource analysis. Micro-algorithm for feature contradiction formulation. Resource-related feature IFR. Micro resource-related feature IFR.

5.2.	Feature IFR. Substance and Field resources (SFR). Micro-algorithm for formulating feature IFR. Principles of solving the contradictions of Features (CF). Application of effect indicators, lines of FOS development in information funds.
6.1.	Analysis and criticism. DTC (dimension – time – cost) method for revealing potential problems. Secondary problems. Questions for revealing secondary problems. Super-effects from changes introduced into the system.
6.2.	Generalization of the problem. Change of the problem and aspect of reviewing. Analysis of operation principle and inverse FOS.
7.	Collector of ideas and chart for problem-solving process.

4. Set of Functions and Transition to Typical Conflict Patterns

A set of functions consists of one or several interrelated function models that describe together one or several problem situations in a source problem. This could be shown on an example of sets of functions for the well–known TRIZ problem of vortex formation by parachute model:

"To study the formation of vortex, a model of a parachute (tower, etc.) is placed inside a glass tube, through which water is pumped. The process is monitored visually. However, colorless swirls are poorly seen against the background of a colorless flow. If we dye the flow, the monitoring will be still more difficult to conduct: black swirls completely disappear against the background of black water. To overcome this difficulty, a thin layer of soluble paint is applied over the model of the parachute – thus colored swirls are obtained against the background of colorless water. Unfortunately, the paint is quickly consumed. If we apply a thick layer of paint, the size of the parachute model is distorted and monitoring becomes senseless. What's to be done?"

Several sets of function models can be identified for this problem. The first option of a set of functions will consist of one function only:

Function 1. The model of the parachute Dyes (changes the color of) Water swirls *(useful, insufficient).*

The second option of a set of functions:

Function 2.1. The dyeing agent dyes (changes the color of) Swirls (useful).
Function 2.2. The water dilutes (decreases the thickness of) Dyeing agent (harmful).
Function 2.3. The dyeing agent dyes (changes the composition of) Water (useful).
Function 2.4. The water generates (changes shape) Swirls (useful).

Based on the algorithm (given below) and Table 2, the type of conflict is determined and the recommended standard solution is found.

Algorithm for identification of conflict type based on the set of functions

1. Main elements are identified as well as functions associated with them (useful and harmful). These sets of functions should be identified as one of the six types of conflicts in the Table 2.

2. If it is known what function is required, but there is no subject of function (X-element), the **1-st** type of conflict is recommended.

3. If there is an insufficient useful function among described functions, the **2-nd** type of conflict is recommended**.**

4. If there are two useful functions, the object of which is one and the same element and at the same time one of the functions is performed insufficiently, the **3-rd** type of conflict is recommended.

5. If among described functions there is a harmful function, the elements of which are inseparably associated with the useful function, the **4-th** type of conflict is recommended.

6. If there is a non-controllable (poorly controllable) useful function among described functions, the **5-th** type of conflict is recommended.

7. If the described functions are associated with measuring, identification or transformation of fields, the **6-th** type of conflict is recommended.

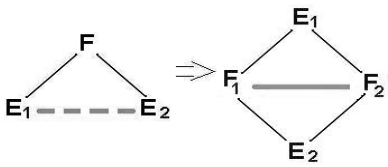
8. If a set of functions includes several types of conflicts, the problem situation is subdivided into several problems with one type of conflict.

Table 2: Table of patterns of typical conflicts and models of problems.

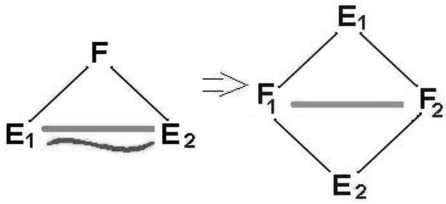
Number and type of conflict	**Description of typical conflicts**	**Recommended solving models**
1. Necessary useful action is missing	No useful action upon element B.	Standard U1.1.
2. Insufficient (incomplete) useful action	Element A performs a useful action in relation to element B incompletely or with insufficient quality.	• Standards U2.1.1, U2.2.1, 2,3 or • Standard U1.1 (replace the element).
3. Incompatible useful actions	One useful function of element A upon element B hinders the implementation of another useful action of element A upon element B.	• Standards U2.1.1, U2.2.1, U2,3. • Exclude the necessity to perform one of two actions (trimming): no necessity for A-B (or C-B) function; the function is performed by a resource element instead of A (C) element; element B performs the function by itself.
4. Harmful function	Counteraction: Element A positively acts upon element B, while element B exerts harmful action upon element A.	• Standard U1.2.1, U1.2.2. • Exclude the necessity for performance of one out of two actions (trimming): ✓ there is no necessity for function A-B (or C-B); ✓ instead of element A (C) the function is performed by another resource element; ✓ element D itself performs this function. ✓ Apply function analysis and trimming. • Standard U1.1 (replace the element A)
	Conjugated action. Element A produces both positive and negative action upon element B. Or useful action is exerted on one part of element B, while a harmful action is exerted upon another part of element B. Or A exerts useful action upon B, but harmful action upon C, which is associated with B. Or A harmfully acts upon itself while performing a useful action upon B.	
5. Unregulated action	Element A acts excessively or insufficiently upon element B.	Standards U2.1.2, U2.2.2.
6. "Silence"	Problems on measuring.	Standard U3.1, U3.2.

For example, function 1 “The mock-up of the parachute Dyes (changes the color of) Water swirls (useful, insufficient)” corresponds to the 2nd type of conflict and standards from universal system of standards U2.1.1, U2.2.1,2,3 or standard U1.1. are recommended for it.

For example, according to standard U2.2.1, it is recommended to introduce an additional field of interaction between the parachute mock-up and water swirls.



For the second option of a set of functions (as applied to the example described above), the conflict is singled out between function 2.2. “Water washes away (decreases the thickness of) Dyeing agent (harmful)” and function 2.3. “Dyeing agent dyes (changes the composition of) Water (useful)”. In other words, the dyeing agent usefully acts upon water, while water harmfully acts upon the dyeing agent. It corresponds to the 4th type of conflict: apply Standards U1.2.1, U1.2.2, Standard U1.1 or eliminate the necessity for performing one of two functions (trimming). According to the Standard U1.2.2, for example, the introduction of an additional field (e.g., electric field) is also proposed.



The control solution for this problem, as it is known, consists in using electrolysis for separating bubbles of gas from water, which would show swirls instead of a dyeing agent. The trimming recommendations also prompt that something else from the resources of the system should be used instead of the dyeing agent, for example, “emptiness” (bubbles).

5. Standards for Inventive Problem Solving

The universal system of standards for inventive problem solving - 2010 [7] is intended for solving problems in engineering and non-engineering systems and is characterized by the following structure:

U1. Synthesis of Ele-fields

U1.1. Creation of Ele-Field structure (new system)

U1.2. Elimination of harmful relationships in Ele-field

U1.2.1 Elimination of harmful relationships through replacement, change or addition of elements

U1.2.2 Elimination of harmful relationships through addition of fields

U2. Development of Ele-field structures

U2.1. Transition to complex Ele-field

U2.1.1. Enhancement of Ele-field efficiency by introducing a component.

U2.1.2. Setting limiting modes for fields.

U2.2. Creation of double Ele-field.

U2.2.1. Enhancement of Ele-field efficiency by introducing a field.

U2.2.2. Setting minimum mode for the element.

U2.3. Creating a chain-like Ele-Field

U3. Synthesis and increasing the efficiency of systems in terms of measurement and identification (systems with features of interaction fields)

U3.1. Roundabout ways

U3.2. Synthesis and increasing the efficiency of systems in terms of measurement and identification

U4. Lines of systems evolution.

U.4.1. Line of introducing components (substances)

U.4.2. Line of introducing and development of interaction fields

U.4.3. Line of segmentation and dynamization
U.4.4. Lines of coordination-discoordination and structurizing
U.4.5. Transition to supersystems and substystems (to micro-level)
U.4.6. Lines of collective and individual use of systems
U.4.7. Lines of systems evolution in accord with S-curves.

6. Formulations of IFR and Contradictions of Requirements

The list of function models enables to propose options for formulations of IFR in the course of problem statement. For example, for the problem (given above), two options of automatically synthesized formulations of IFR are possible: X-element ITSELF makes unnecessary the performance of function dyes (changes color of) swirls. Or the second option: X-element ITSELF performs function dyes (measures the color of the object) the swirls.

Selection of an IFR option by the user enables to automate the process of formulating the options of requirements contradictions. For example, for the first formulation of IFR we have the following: IF we use dyeing agent as X-element, THEN the following function is performed: "X-element dyes the mock-up of the parachute, BUT, the constraint "The shape of the model shall not be distorted" is violated.

7. Peculiarities of Selecting Principles for Resolving Contradictions

Transition from the contradiction of requirements (engineering contradiction) to principles for resolving them is usually conducted using the Altshuller's Table [2]. However, the analysis of the set of function models enables to do it without using this Table or to refine the list of principles proposed based on it or to refine their priority. The following algorithm could be used for that:

- Identify the areas of intersection of time and space of action of useful and harmful actions based on the analysis of a set of functions.

- Identify the principles for resolving contradictions, which are recommended for this particular situation, using Table 3.

- Compile a list of principles, which correspond to the selected principles for resolving contradictions (the corresponding list is developed based on publication [9]); the list could include not only 40 basic principles, but also additional ones [10]. First of all, those principles are singled out, which concurrently correspond to several principles for resolving contradictions.

- Then, Altshuller's Table is used to augment the list of recommended principles; a higher rank is assigned to principles, which coincided with the recommended ones prior to using the Altshuller's Table.

- If a problem for a non-engineering (non-material) system is to be solved, then lines, columns and principles of Altshuller's Table that refer to engineering systems only (e.g., replacement of a mechanical scheme, thermal expansion, phase transitions, etc.) [11] are disregarded.

Table 3: Table of recommended principles for resolving contradictions

Time of conflict and time of useful action / Zone of useful action and the zone of non-desirable effect	**Don't overlap**	**Partly overlap**	**Coincide completely**
Don't overlap	• In time • In space (direction)	• In space (direction) • In time	• In space • System transition

	• In relation	• In relation	• Physical-and-chemical and phase transitions • In relation
Touch one another	• In time • In relation • System transition • Physical-and-chemical and phase transitions	• In space (direction) • In time • In relation • Physical-and-chemical and phase transitions	• In space (direction) • System transition • In relation • Physical-and-chemical and phase transitions
Overlap	• In time • System transition • Physical-and-chemical and phase transitions In relation	• System transition • Physical-and-chemical and phase transitions • In relation	• System transition • Physical-and-chemical and phase transitions • In relation

For the example given above (the second option of a set of functions), two conflicting functions were identified: function 2.2. “Water washes away (decreases the thickness of) Dyeing agent (harmful)” and function 2.3. “Dyeing agent (changes the composition of) Water (useful)”. Operation time and operation zone of harmful and useful action coincide. This situation corresponds in Table 3 to cell 3-3, it means that the following principles are recommended: system transition, Physical-and-chemical and phase transitions, In the relation.

When comparing several dozens of principles related to these three principles for resolving contradictions, six principles are repeated: Segmentation (1), Integration (5), Porous materials (31), Multi-stage action (42), Bi-principle (45), Dissociation-association (49). It means that recommendations on the use of principles for resolving contradictions can be offered even before addressing Altshuller's Table.

It is possible to differently select lines and columns of the Altshuller matrix for this problem. For example, one could select the pair: line 8 (Volume of immobile object) and line 31 (Harmful factors of the object proper). We obtain recommendations for using four principles: #30 (Use of flexible shells), #18 (Use of mechanical oscillations), #35 (Variation of physical-and-chemical parameters of the object), and #4 (Asymmetry). If we take into account the recommendations based on the recommended principles of resolving contradictions, only 2 principles will remain out of 4: #18 (Use of mechanical oscillations), and #35 (Variation of the physical-and-chemical parameters of the object). These are more accurate recommendations.

The proposed approach enables to develop methods for automation of transition from problem model to recommended principles for inventive problem solving.

8. Experience of Practical Use

ARIZ-U-2014 has been used in the practice of inventive problem solving and at training seminars since 2013 with students, teachers, researchers and engineers. This experience showed the efficiency of ARIZ-U-2014, it is easier for mastering and quicker leads to finding solutions for problems.

The software complex COMPINO-TRIZ is being developed based on ARIZ-U-2014 (joint work with S.S.Sysoev is in progress). COMPINO-TRIZ significantly accelerates the process of analysis, helps even those, who only start to learn TRIZ, to use ARIZ. One of the disadvantages of software implementation of ARIZ-U-2014 is the obtainment of such formulations of functions, IFR and contradictions, which are not always coordinated in terms of the language rules.

Conclusions

1. Proposed version of ARIZ-U-2014 enables to formulate and solve inventive problems not only in technology, but also in non-engineering areas. Owing to the functional approach to formulation of models of problems and solutions, it became possible to formalize the process of creating formulations of contradictions, IFR, recommended standards for solving inventive problems and other steps of ARIZ.

2. Research work showed that the analysis of systems functions, which has been developing in TRIZ during the last decades, is an addition, not an opposition to the analysis of contradictions and Su-Field (Ele-Field) analysis. The integration of these kinds of analysis yields qualitatively new opportunities for analyzing and solving the inventive problem.

3. It is possible to single out a new tendency in the development of TRIZ tools: their further formalization and making them more detailed leads to a possibility of their computer-assisted implementation and to making their use easier in the practice of inventive problem solving and in teaching TRIZ.

4. Automation of formulations of ARIZ steps enhances the efficiency of using it in the practice of inventive problem solving, innovative design and studying TRIZ at training courses.

References

1 . Altshuller G.S., Shapiro R.B. Psychology of Inventive Activity. – Voprosy psikhologii, 1956, No. 6, pp. 37-49.

2. Altshuller G.S., Algorithm of Invention, M., “Moskovsky rabotchy publishers”, 1973.

3. Altshuller G.S., ARIZ Means Victory. Algorithm of Inventive Problem Solving ARIZ-85-C.- Rules of Game without Rules / Compiled by A.B.Seliutsky. – Petrozavodsk: Karelia, 1989.-280 p. - (“Technology – Youth – Creativity”), pp. 11-50.

4. Zlotin B.L., Zussman A.V., Litvin S.S., Petrov V.M. et al. Collection of publications on ARIZ-91, Leningrad, 1991, http://www.triz-summit.ru/ru/205253/203840/204230/204231/

5. Petrov V.M., Rubin M.S. Requirements to the development of ARIZ of new generation. Scientific-and-practical conference “TRIZfest-2009”: collection of conference papers. SPb, 2009. – 302 p.p. 159-165). http://www.triz-summit.ru/ru/section.php?docId=4201

6. Petrov V.M. History of Creation of Algorithm for Inventive Problem Solving – ARIZ. Second edition, Tel-Aviv, 2008. http://www.triz-summit.ru/file.php/id/f3975/name/History%20of%20ARIZ-book.rar

7. Rubin M.S. Universal system of standards for inventive problem solving – 2010. Version dated February 18, 2012. www.triz-summit.ru/ru/203798/205151/205266/205416/205422/

8. Rubin M.S. ARIZ-Universal-2010. Version dated July 15, 2012. http://www.triz-summit.ru/ru/203798/205151/205266/205416/205301/

9. Litvin S.S. Techniques for resolving physical contradictions. – Leningrad, February 1981. – 11 p.p., manuscript.

10. Altshuller G.S. Additional list of techniques for elimination of engineering contradictions, Baku, 1973, http://www.altshuller.ru/triz/technique1a.asp

11. Rubin M. S. Fundamentals of TRIZ. Application of TRIZ in programming and informational systems: a manual. – SPB, ATM “Kniga”, 2011.

Author (co-author) to contact: Mikhail Rubin, mik-rubin@yandex.ru

TRIZfest 2014

Practical Application of the TRIZ-Assisted Stage-Gate Process

Oleg Y. Abramov

Algorithm Ltd., 16 Ruzovskaya Street, St. Petersburg, 190013, Russia

Abstract

This paper relates to the practical application of the TRIZ-Assisted Stage-Gate process for developing new products. This process is obtained by integrating TRIZ tools into the Stage-Gate process, which is the most frequently used best industry practice for new product development. The paper includes a brief case study on the development of a novel Smart Antenna for Wi-Fi systems that illustrates the practical implementation of the TRIZ-Assisted Stage-Gate process, and which has confirmed its high efficacy in terms of speeding up the development, decreasing cost and reducing associated risks. Also, recommendations in what cases the use of the TRIZ-Assisted Stage-Gate process is critical and in what cases the Stage-Gate process can be safely employed alone are given in this paper.

Keywords: New Product Development; Stage-Gate process; TRIZ.

1. Introduction

Modern industry has developed its own best practices such as the Stage-Gate process [1], which is widely used for developing new products and demonstrates superior efficacy relative to ‘undisciplined development’.

However, if a new product is truly innovative and requires solving difficult inventive problems, the Stage-Gate process frequently introduces great delays or even fails, and, so, many promising ideas either have never been developed into products or their development took much more time and money than was initially expected. People in the industry perceive these setbacks as inevitable.

In order to improve the situation, the author has proposed integrating TRIZ and GEN3 TRIZ [2] tools into the Stage-Gate process so as to obtain a TRIZ-Assisted Stage-Gate process [3,4] that employs TRIZ tools throughout the entire development - from idea generation to commercial prototype. This process is expected to drastically improve the efficacy of the Stage-Gate process. Moreover, when developing a truly innovative product that requires solving complex technical contradictions and/or involves solutions from distant areas of engineering, this new method could well save a project that would otherwise fail.

In this paper, based on an example of the practical implementation of the TRIZ-Assisted Stage-Gate process, the author is trying to:

1. Show that this process meets these expectations and actually reduces risks associated with the development;

2. Formulate recommendations when using this process is absolutely critical and when the Stage-Gate process alone can be successfully employed.

2. How TRIZ Addresses Weaknesses in the Original Stage-Gate Process

2.1. Pitfalls of the Stage-Gate process

The Stage-Gate process [1] has five stages where rough ideas are consecutively developed into a commercial product, and between each of the stages is a gate at which strategic decisions are made about whether an idea, concept, or design should be developed further.

Due to a well-developed and detailed step-by-step algorithm for its implementation, the Stage-Gate process significantly reduces development time and cost relative to ’undisciplined development‘ because unpromising ideas, prototypes and designs are rejected at earlier stages and do not consume resources and time after that.

However, despite its recognized efficiency, the Stage-Gate process sometimes fails to yield a viable product. Below are examples of pitfalls that the author has repeatedly seen in this process:

1. Ideas of the product generated at the Discovery stage and decisions on what ideas to proceed with further are normally based solely on the input provided by marketing people. This input represents ‘voice of the customer’ as it is perceived at the moment, and, so, there is a risk that either the voice of the customer may change during the development and the product will not be needed anymore, or the idea selected for further development is unfeasible, and, therefore, will never be implemented.

2. At Stages 1 and 2, engineering problems associated with developing a totally new engineering system (ES) are normally solved by a team of engineers with expertise in the field related to this particular ES. At this point, however, good solutions may sometimes be found in distant areas of engineering not being considered by the team. This may result in the implementation of imperfect solutions or even the rejection of a good idea.

3. At Stage 3, implementation problems may appear that are so difficult that the development team will be unable to solve them, especially if the solution is beyond the team’s area of industry and science. Such implementation problems may appear because, for example, constraints and requirements imposed by marketing or manufacturing people are too rigid.

4. At Gates 2, 3, and 4, a concept or prototype design may be rejected because it is thought that it might infringe a 3rd party’s intellectual property (IP). Even a small risk of infringement identified by patent attorneys could lead to rejecting a good concept that may require just a minor modification to circumvent the obstructive 3rd party’s IP.

5. Even at the testing and validation stage (Stage 4), severe problems sometimes arise when the new product requires new testing methodology that does not yet exist. Inability to test the product and convince consumers of its benefits may greatly delay or make it impossible to commercialize the product, which will result in rejecting the product at Gate 5.

It would be fair to say that in most cases a development goes through the Stage-Gate process smoothly, especially if a new product is not very different from the old one, which the development team is thoroughly familiar with. However, even in this case some of the above-listed pitfalls may manifest themselves and delay the development.

These pitfalls become especially critical when the development relates to a highly innovative product that is completely new to the development team. In this instance the development normally experiences delays and frequently ends unsuccessfully.

The reason for this is that the Stage-Gate process doesn’t include tools to efficiently address all of the technical problems that arise during the development of a truly innovative product as they may require knowledge and skills outside the developers’ area of expertise.

2.2. Tools that TRIZ Brings to Address Pitfalls of the Stage-Gate Process

The TRIZ-Assisted Stage-Gate process, proposed by the author [3, 4], addresses the above-listed Stage-Gate process's pitfalls by consistently employing TRIZ and GEN3 TRIZ tools throughout the development (see Fig. 1).

At the same time, this approach retains the general structure of the Stage-Gate process intact, which facilitates its implementation where the Stage-Gate process is already being used.

As shown in Fig. 1, TRIZ tools employed in the TRIZ-Assisted Stage-Gate process are 'stage-specific', that is different tools are used at different stages of the process:

• At the Discovery stage, the most useful tools are Trends of Engineering System Evolution (TESE) and Main Parameters of Value (MPV) [5] analyses: TESE analysis brings 'voice of the product' to the development, which allows for generating more feasible product ideas; MPV analysis yields features that need to be implemented in the product.

• Introducing TESE analysis for screening product ideas generated at Gate 1 and concepts developed at Gate 2 is an efficient way to identify and reject less promising ideas and concepts that contradict the objective trends of the product's evolution.

• At Stage 1, when the ideas for a new product are being developed into concepts, all tools aimed at identifying and solving Key Problems [6] can be employed. The most useful tools at this stage are Cause and Effect Chains Analysis of disadvantages (CECA) [7], Function Oriented Search (FOS) [8], ARIZ, etc.

• At Stage 2, problem solving tools such as FOS, ARIZ and Contradiction Matrix with the 40 principles for solving engineering contradictions (ECs) are used to speed up development of the selected concepts into proof-of-principle prototypes and generate concepts for working prototypes.

• At Gate 3, GEN3 TRIZ tools for identifying secondary technical problems [9] are used to enhance the efficiency of screening the concepts for working prototypes.

• At Stage 3, when the product is being further developed into working prototypes and production prototypes, TRIZ and GEN3 TRIZ tools are used less extensively, but, nevertheless, the following tools can greatly contribute to the development:

- Comprehensive Analysis [10] aimed at identifying not only technical problems, but other problems as well, such as potential infringement of 3rd party IPs;

- Trimming, a tool for reducing product cost by eliminating some components of the product without changing its overall functionality;

- Competitive Patent Circumvention [11] helps to avoid infringing competitive IP.

• At Stage 4, and sometimes even at Stage 5, TRIZ and GEN3 TRIZ tools are used as needed, but normally they are less critical at these stages.

As can be seen from Fig. 1, TRIZ tools are particularly useful at the initial stages of the development – from the very beginning through Stage 3 – while at later stages these tools generally become less critical.

The practical application of the TRIZ-Assisted Stage-Gate process has shown its efficacy and ability to yield a new promising product in a situation when the Stage-Gate process would otherwise fail (see next section).

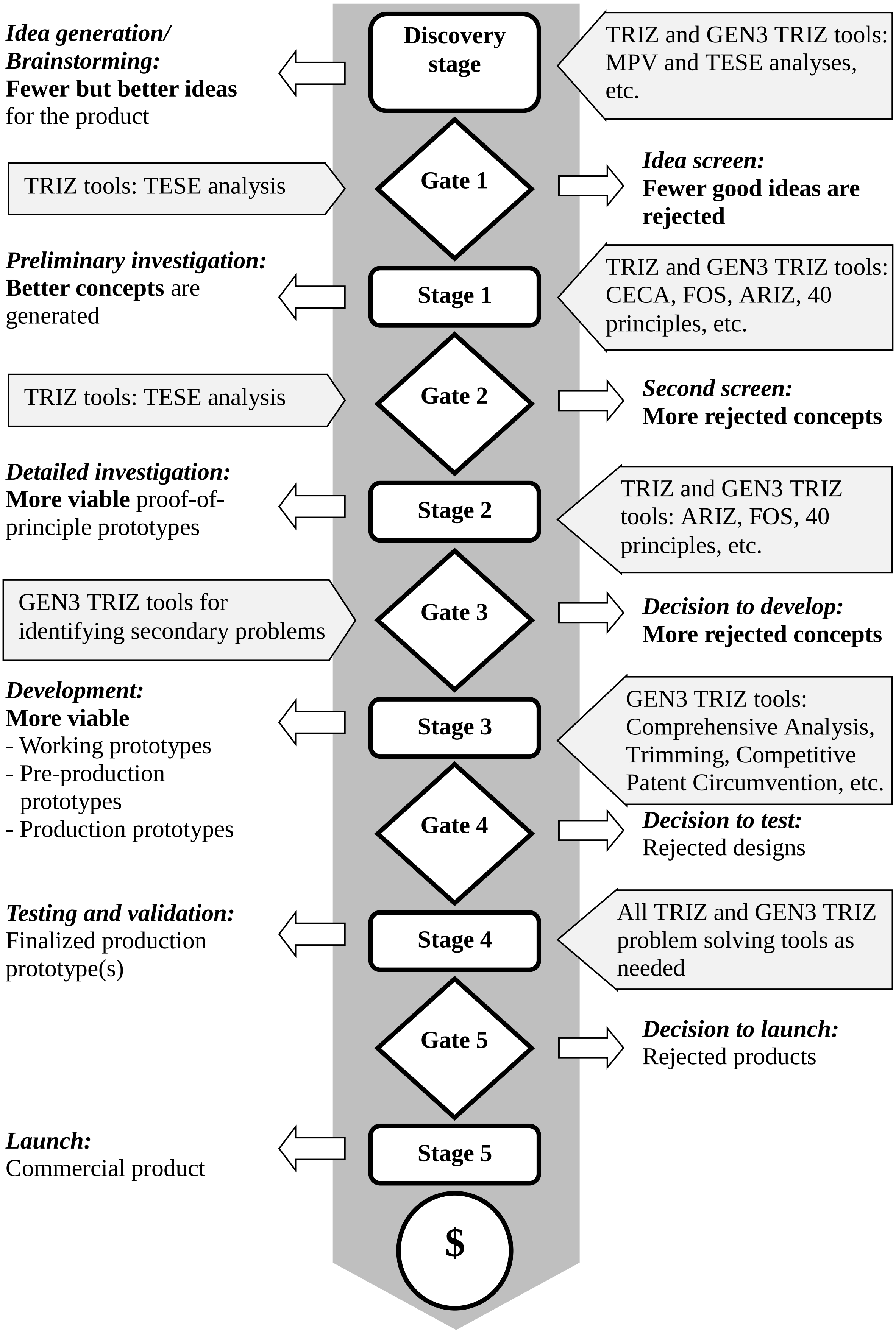


Fig. 1. The TRIZ-Assisted Stage-Gate process map [4]

3. Example of the Practical Implementation of the TRIZ-Assisted Stage-Gate Process

3.1. Background

The TRIZ-Assisted Stage-Gate process was successfully implemented in a series of TRIZ-consulting projects performed by a GEN3 team for Airgain, Ltd., a California-based startup company, in 2000-2010. During this period, Airgain and GEN3 had an FTE contractual agreement in place that allowed a GEN3 team lead by the author to contribute to the development of several products for Airgain.

All these products were Smart Antennas (SA) for various Wi-Fi systems, such as Wi-Fi routers, embedded and external Wi-Fi cards, Wi-Fi-enabled set-top boxes, etc. (a Smart antenna is an antenna system that automatically focuses its beam in the direction that provides the best signal quality and, so, dramatically improves communication range and speed.)

At the Discovery Stage of the first project in 2000, the idea of incorporating an SA into a Wi-Fi system was generated by the GEN3 team based on the results of an MPV analysis. This analysis revealed that the most valuable MPV of a telecommunication system is the signal-to-noise ratio (SNR), which, as it increases, can be translated into larger communication range/coverage area or higher communication speed. The team also identified that the most promising way to improve the SNR is to increase the antenna gain, which requires using a steering-beam Smart Antenna.

Implementing an SA in a Wi-Fi system was quite a new idea and represented a challenging task as it required solving several engineering contradictions. Previously, SAs had only been used in big and expensive systems, such as military radars and cellular towers.

Using TRIZ tools, the GEN3 team solved all of the technical problems and by 2003 prototypes of inexpensive SA-enabled Wi-Fi devices in the form of a desktop ‘tower’ module were built, tested and patented [12]. Soon after, Airgain became an antenna company, which produced and sold various SAs to Wi-Fi equipment manufacturers.

Described below is an example of the practical implementation of the TRIZ-Assisted Stage-Gate process for developing one of these SAs, namely, Airgain MaxBeam75, which progressed through the complete development cycle from idea to commercial product.

3.2. Using TRIZ-Assisted Stage-Gate Process in Developing Airgain MaxBeam75 Smart Antenna

In 2003, Airgain’s marketing people identified a need in the Wi-Fi market for an SA which fits inside a flat box. At that time most manufacturers of Wi-Fi equipment were already producing their modules in such a box and were no longer interested in buying Tower SAs. The overall dimensions of the new antenna were specified at 15x100x100 mm (HxWxL).

The biggest problem was that the antenna’s profile had to be very low (15 mm), far lower than the height of the half-wave vibrator (basic antenna element), which at Wi-Fi frequency is about 60 mm. Using 15-mm vibrators would drastically decrease the SA performance, which was unacceptable as the performance had to exceed that of the half-wave vibrator.

Airgain engaged the GEN3 team to solve this engineering contradiction and develop the required antenna from scratch. Fig. 2 highlights the development process and indicates what TRIZ and GEN3 TRIZ tools actually contributed to the development.

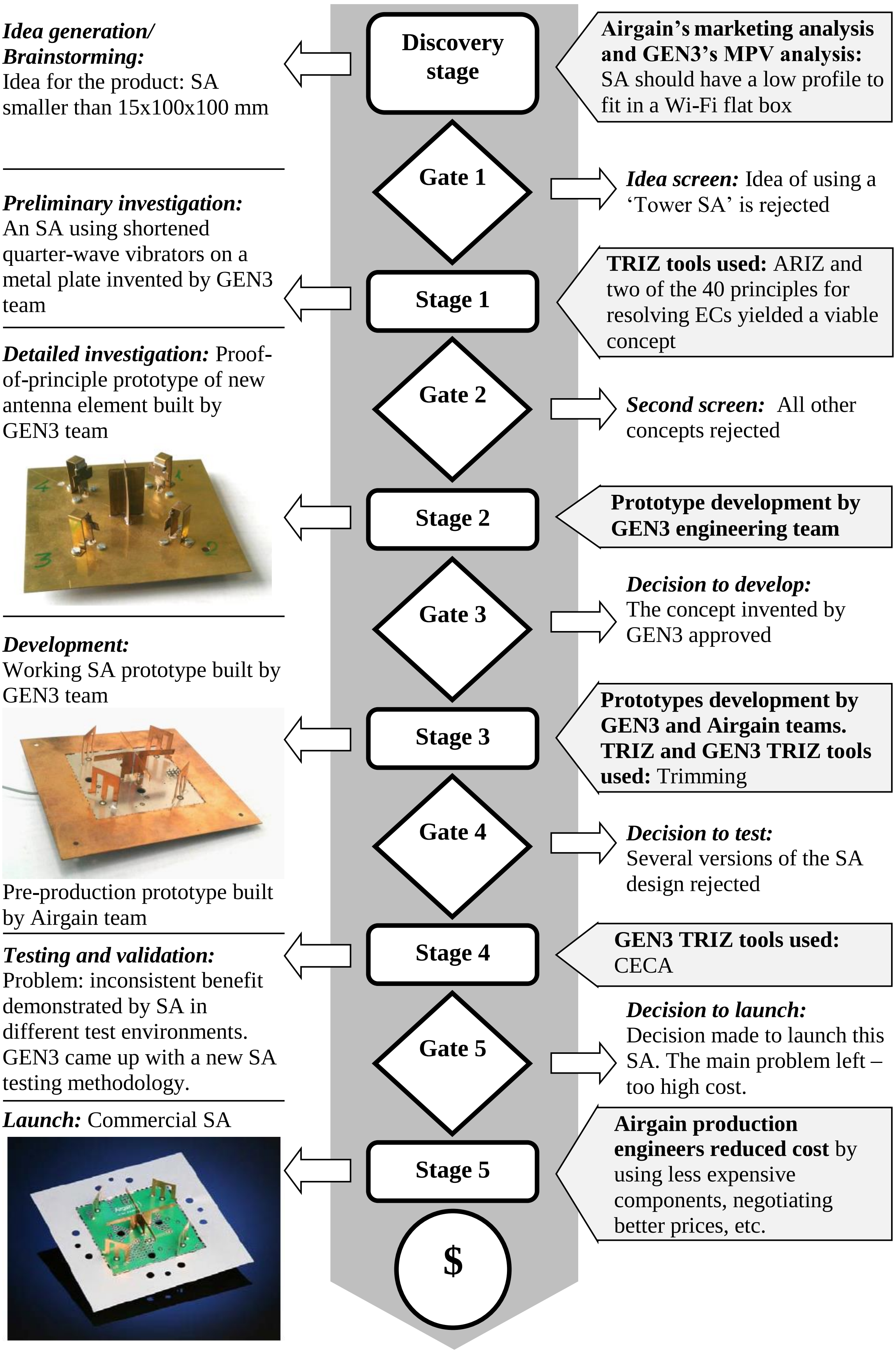


Fig. 2. Airgain MaxBeam75 smart antenna development map [4]

As shown in Fig. 2, TRIZ and GEN3 TRIZ were actually used through stage 4 (testing) of the development:

• At Stage 1, ARIZ and Contradiction matrix with the 40 principles led to the idea to install shortened quarter-wave vibrators on a conductive metal plate. An SA with such elements met the requirement for having a 15-mm profile. This solution utilized the following principles of solving technical contradictions:

- Principle 26 - ‘Copying’: quarter-wave antenna elements use their “reflections” in the metal plate (at the SA’s operating frequency, the metal plate acts like a mirror) and effectively work like regular half-wave vibrators. This allowed for a two-fold reduction in the antenna height – from ~60 mm to 30 mm.

- Principle 17 - ‘Another dimension’: new antenna elements were made two-dimensional as opposed to the original single-dimensional half-wave vibrator, which made it possible to further reduce the antenna height to the required 15 mm.

• At Stage 3 Trimming was used in order to reduce the number of SA elements so as to meet the requirement for having a 100x100mm SA footprint. As a result, all reflector elements in the antenna were replaced with a single reflector surrounded by active antenna elements, which dramatically reduced the SA footprint.

• At Stage 4, the GEN3 team used the Cause-Effect Chain Analysis of disadvantages to identify why the results of an SA testing were inconsistent in different environments.

It should be mentioned that at two critical moments during this project both the development and Airgain itself were under threat. If the GEN3 team had not found solutions for the problems encountered, the development would have been cancelled and the company could have gone bankrupt.

The first critical moment occurred at Stage 1 when an important client of Airgain wanted to see a concept of the SA that met both dimension and performance requirements simultaneously. The client set a tough deadline for delivering the concept, but Airgain engineers did not have a good solution. In this situation the GEN3 team, using TRIZ tools, were able to quickly come up with a viable concept.

The second critical moment came at Stage 4: tests of the developed MaxBeam75 SA at the client’s facility did not reveal any benefit of this antenna when compared to a regular dipole antenna, while at the Airgain lab an impressive benefit had been measured in all of the tests. Airgain engineers spent a few months trying to identify the reason for this discrepancy. Finally, the client set a deadline for solving the problem and Airgain again engaged the GEN3 team.

Using CECA, the GEN3 team found that the measured benefit was inconsistent because the testing methodology employed had not been designed for use in a multipath environment. The GEN3 team came up with a new methodology for over-the-air field testing of Wi-Fi systems [13], which was eventually adopted by Airgain and submitted to an IEEE802.11t task group. Later this methodology became an important part of Airgain antenna technology.

With the exception of these two critical moments, the development went smoothly through the TRIZ-Assisted Stage-Gate process and yielded a commercial NaxBeam75 SA that was patented [14] and successfully commercialized.

In January 2007 this antenna won an award from the government of California as the most innovative product of 2006 in the communications category [15].

4. Discussion of the Results

Practical implementation of the TRIZ-Assisted Stage-Gate process has confirmed its high efficiency in terms of reducing a development's time and cost. Based on the author's estimation, the TRIZ-Assisted Stage-Gate process reduced the overall development time of Airgain MaxBeam75 SA by about three to five months at stages 1 through 4.

Moreover, the development of Airgain MaxBeam75 SA would have been stopped and this product would not have appeared at all if TRIZ tools had not been used at the right time. This, in fact, seems to be a fairly common situation: the author has witnessed quite a number of cases when the Stage-Gate process failed and promising developments were stopped just because TRIZ tools were not used.

During the development of Airgain MaxBeam75 SA, the roles of Airgain and GEN3 teams changed exactly as described in other papers [3, 4]:

• The role of the GEN3 team was especially important at the initial stages of the development and remained critical until the working prototype was built and tested;

• At the final stages, the Airgain team took over the development while the GEN3 team supported it as needed.

No major organizational difficulties were experienced with implementing the TRIZ-Assisted Stage-Gate process in the Airgain MaxBeam75 SA development and in other developments that the GEN3 team performed for Airgain.

It would be fair to mention, however, that the TRIZ-Assisted Stage-Gate process does not yet represent a fully optimized methodology as its practical, full-scale implementation is limited to just one project. On the other hand, all parts of this process were separately tested and refined by the author in a number of projects at various stages of new product development.

Also, it has to be said, that there are many cases, such as ongoing developments, where using the TRIZ-Assisted Stage-Gate process is not critical and Stage-Gate process alone yields good results. For example, all Airgain antennas developed with the help of the GEN3 team, including Airgain MaxBeam75 SA, were further developed and modified/customized as needed solely by the Airgain team.

5. Conclusions

In the project described above, the TRIZ-Assisted Stage-Gate process did provide a significant reduction in development time and cost. Moreover, using this process saved the development and yielded a successful product in a situation where the Stage-Gate process alone would otherwise fail.

Yet, in order to better estimate all benefits provided by the TRIZ-Assisted Stage-Gate process, it is necessary to implement it in more projects. Extensive practical implementation may also yield a necessity to further refine this process so as to make it even more efficient.

Implementation of the TRIZ-Assisted Stage-Gate process assumes including TRIZ-experts in the engineering development team at all stages of the development. This is important.

Using this process is critical for developing truly innovative products that:

1. Require solving severe technical contradictions starting from the early stages of the development, and/or

2. Involve solutions from areas of engineering that are far from that of the product been developed and, therefore, which the product development team is not familiar with.

Only the less innovative products in many cases can be successfully developed using the Stage-Gate process without involving TRIZ tools.

References

1. Stage-Gate International. “New Product Development Process.” The official site of Stage-Gate® . http://www.stage-gate.com/knowledge_stage-gate_full.php, accessed July 2014.

2. GEN3 Partners, Inc. “Our Approach.” GEN3 Partners Web site. http://www.gen3partners.com/methodology/innovation-processes, accessed July 2014.

3. Abramov, Oleg Y. ”Industry Best Practices And The Role Of TRIZ In Developing New Products.” Proceedings of TRIZfest 2013 Conference, Kiev, Ukraine, August 1-3, 2013, pp.229-235.

4. Abramov, Oleg Y. “TRIZ-assisted Stage-Gate process for developing new products.” June 8-11, 2014, The XXV ISPIM Conference – Innovation for Sustainable Economy & Society Conference Paper. ISPIM Web site. http://ispim.org/files/2014_dublin_proceedings/567121536_Paper.pdf, accessed July 2014.

5. Litvin, Simon S. “Main Parameters of Value: TRIZ-based Tool Connecting Business Challenges to Technical Problems in Product/Process Innovation.” September 9, 2011, 7th Japan TRIZ Symposium Conference Paper. Japan TRIZ Society Web site. http://www.triz-japan.org/sympo2011/EI01eS-Litvin_(Keynote)-110817.pdf, accessed July 2014.

6. GEN3 Partners, Inc. “Key Problems.” GEN3 Partners Web site. http://www.gen3partners.com/methodology/innovation-processes/key-problems, accessed July 2014.

7. Litvin, Simon S. “G3:ID Application to Developing Products for Emerging Markets.” November 17, 2011, 4th International Congress on Innovation Conference Paper, pp. 34-40. FIERGS system Web site. http://www.fiergs.org.br/files/arq_ptg_6_1_9717.pdf, accessed July 2014.

8. GEN3 Partners, Inc. “Adapt Existing Solutions, Don't Always Invent.” GEN3 Partners Web site. http://www.gen3partners.com/methodology/innovation-processes/function-oriented-search, accessed July 2014.

9. Abramov, Oleg Y. “Identifying Secondary Problems in Engineering Systems at the Transitional Stage of Their Evolution.” July 31, 2012, TRIZ Developers Summit 2012 Conference Paper. TRIZ Developers Summit Web site. http://www.triz-summit.ru/file.php/id/f5436/name/TRIZ-Summit%202012%20material_Abramov_ENG.pdf, accessed July 2014.

10. Abramov, Oleg Y. “Comprehensive Analysis of Engineering Systems at the Transitional Stage of Their Evolution.” TRIZ Master diss., The International TRIZ Organization, 2012. TRIZ-Summit Web site. http://www.triz-summit.ru/file.php/id/f5467/name/Abramov%20TRIZ-Master%20Thesis%202012_Abstract_ENG.pdf, accessed July 2014.

11. GEN3 Partners, Inc. “IP Strategy.” GEN3 Partners Web site. http://www.gen3partners.com/services/ip-strategy, accessed July 2014.

12. Abramov O.Y., Kashkarov A.G., Kirdin, A.N. (2002), Direction-Agile Antenna System for Wireless Communication, US Patent 6486832.

13. Pertti Visuri, Oleg Abramov, “Over the Air Field Testing of 802.11 Systems,” Airgain, Inc. Web site,

http://www.airgain.com/pdfs/Over_The_Air_Field_Testing_for_80211_Systems_opt.pdf, accessed July 2014.

14. O.Y.Abramov et al. (2007), Switched Multi-Beam Antenna, US Patent 7215296.

15. Electronic Desin. “Miniature Smart Antenna Wins Innovation Award.” January 9, 2007. http://electronicdesign.com/energy/miniature-smart-antenna-wins-innovation-award, accessed July 2014.

Author (co-author) to contact: Oleg Abramov, *Oleg.Abramov@algo-spb.com*

TRIZfest 2014

RCA+ Evaluation Based on Vague Data

Tomas Kisela[a,b]

[a] *SC&C Partner, Brno, 621 00, Czech Republic*

[b] *Brno University of Technology, Brno, 616 69, Czech Republic*

Abstract

During Root Conflict Analysis (RCA+) session, the team usually tends to discuss the studied issue in broad context and from different angles. However, the RCA+ diagram collects only the cause/effect statements and their causal links, while other revealed information relevant to the problem might be lost.

For instance, consider a situation when a listener does not understand a speaker. If we place a cause „the speaker's voice is too still" into the RCA+ diagram, it means that the voice is still enough to be unintelligible for the listener. But we usually have a closer feeling about the extent of the stillness. Whether the voice is barely audible and there is no chance to understand, or whether the lack of loudness can almost be compensated by intensive concentration. Similarly, if we think of several independent causes of an effect, we often have an idea about frequency of their occurrence. Both these examples represent situations when exact data are usually not available and only vague information formed by a mix of opinions and insights are provided.

This paper proposes a method enabling to capture such additional information appearing during RCA+ sessions and to leverage it for ranking and selection of contradiction causes. To deal with the vague character of this knowledge, we employ some notions originating from the so-called fuzzy logic which is designed for reasoning based on uncertain data.

Keywords: Root conflict analysis, Evaluation, Fuzzy numbers.

1. Introduction

Root Conflict Analysis (RCA+) is a relatively new tool supporting the flagship of TRIZ, i.e. solving of technical and physical contradictions. RCA+ is a team technique based on building a causal model which enables a systematic comprehensive identification of underlying contradiction causes of the problem. In spite of its short history, RCA+ managed to significantly expand and by many TRIZ users it is now considered to be one of the fundamental TRIZ tools (see, e.g. [1,2]).

Throughout this paper we are going to employ the standard notation utilized in the literature (see, e.g. [1,2,3]). Regarding the cause/effect classification, we observe four possible cases, namely negative, positive, contradiction and non-changeable one (see Figure 1).

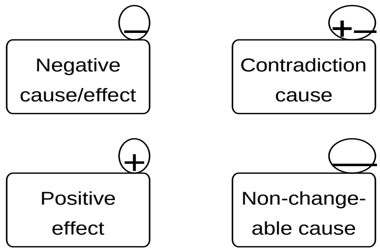


Fig. 1. RCA+ notation: Types of causes/effects

In RCA+ diagram we distinguish between two possible logical connections between causes and effects. If an effect can occur as a consequence of cause A as well as cause B, we say that the causes A, B are in „or" relationship (we also call them independent). If an effect occurs only as a result of both causes A, B, we speak of „and" relationship (see Figure 2). For detailed guidelines how to perform RCA+, we refer to, e.g. [2,3].

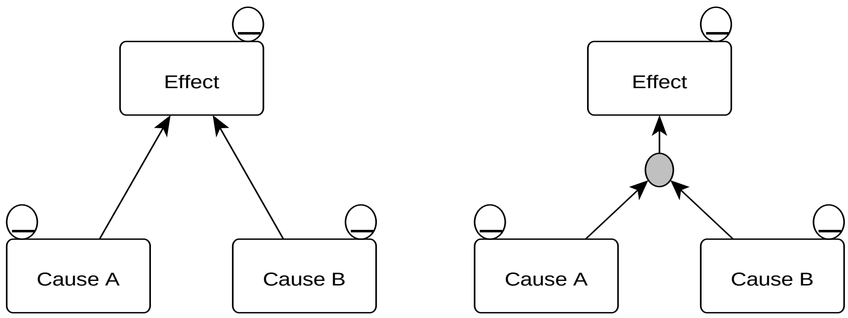


Fig. 2. RCA+ notation: Representation of "or" and "and" relationships, respectively

After RCA+ diagram is completed, the original problem is decomposed into a tree structure whose roots are formed by contradiction or non-changeable causes. Further, it is expected to rank and select the contradiction causes in order to prioritize next activities and maximize chances to find a strong and feasible solution. Current evaluation techniques are based on criteria assessment via comparative ranking or numerical value comparison. The former approach utilizes expert knowledge of the team members which is usually easy to extract, however it can be quite time-consuming in cases concerning numerous contradiction causes and multiple criteria due to a huge number of possible combinations. The numerical value comparison is easier to work with and evaluate, but it relies on an ability of team members to agree on values to be assigned with all criteria for all contradiction causes. Besides the tardiness of arguments preceding reaching a compromise, some team members are usually not fully identified with achieved results.

The main goal of this paper is to propose an evaluation technique originating from theory of fuzzy sets and numbers, (see, e.g. [4]) combining the advantages of both the above-mentioned approaches. It enables us to use expert estimates given in terms of linguistic statements (e.g. "rarely", "medium" etc.) as criteria values, i.e. it removes the need for reaching a general compromise and therefore it accelerates criteria assessment. At the same time, these linguistic statements can be treated almost as easily as numerical values.

The paper is organized as follows. Section 2 is devoted to classical RCA+ evaluation methods. In particular we recall some basic criteria used for ranking and selection of contradiction causes and suggest two new ones. Next we deal with the idea of combined criteria and demonstrate it on an example. Section 3 concerns with a generalization of this method in terms of an introduction of fuzzy values for evaluation criteria. The paper is concluded by Section 4 where several aspects of this approach are briefly discussed.

2. RCA+ Evaluation Technique

When RCA+ diagram is completed, several contradictions contributing to the original negative effect are identified. Usually we do not need to deal with all of them to remove the original problem therefore there is an urge to pick just the ones leading us to the best possible solutions. There is no way how to ensure the quality of the result which are unknown yet, therefore we mostly rely on expert estimates and heuristic criteria such as comparative ranking, ideality-based criteria or “root” criterion (see, e.g. [2,3]).

In this section we present some known as well as new approaches to this matter and introduce a notion of combined criteria enabling us to take into account several viewpoints at the same time. An illustrative example is presented at the end.

2.1. Some Selection Criteria

Selection criteria utilized after RCA+ are designed to suggest a contradiction cause possibly leading to solutions with the highest degree of ideality growth (see, e.g. [3]). That means removing problems (value reducers) at the lowest costs (money, time etc.) with preserved or increased useful functions of the system (value creators). Obviously, this generic idea does not yield any specific criteria but turns our focus on the most promising directions.

The easiest situation occurs when we face independent contradiction causes. To remove the effect, all such causes have to be eliminated. However, if we need to prioritize then we can base our decision on the criterion which can be called

Importance (C1) – Choose the contradiction cause which contributes the most to the general problem. It can be assessed e.g. via comparative ranking, frequency of occurring (if the data are available) etc.

If we meet a number of contradiction causes in “and” relationship, the situation is more complicated since all of them have the same C1 criterion. Thus, we usually try to somehow foresee possible costs and get criteria such as

Simplicity (C2) – Choose the contradiction cause that involves the minimal number of elements.

Susceptibility (C3) – Choose the contradiction cause that is formed by elements that are easy to change or influence (the change can be viewed from various angles, such as costs, strategy, rights etc.).

Most of the criteria usually discussed in literature and used in practice, fall into one of the categories C1-C3. However, in some cases it might be convenient to take into consideration also another aspect. Contradiction causes can be divided into two large groups. First, we have causes depending on whether some situation occurs or not (e.g. finger touches a screen, ice melts, absence of oxygen). Second, we have causes concerning values of a parameter or its change (the keyword „too“ is utilized, e.g. weight is too high). That enables us to discuss the extent to which the cause exceeded the acceptable level. While in the case of the first group we have only binary values (0 – does not occur, 1 – occurs), the second group provides a new way of contradiction causes assessment.

Extent (C4) – Choose the contradiction cause which key parameter is the most far from switch value, i.e. a critical value of the parameter for which the effect starts or stops being produced.

In particular, if we find a key contradiction cause parameter, its switch value (when the effect appears and disappears), its extreme value (limit of parameter while effect is produced) and its current value, we can quantify the extent as a normalized ratio

$$\text{Extent} = \left| \frac{\text{current value} - \text{switch value}}{\text{extremal value} - \text{switch value}} \right| .$$

It enables us to compare and rank contradiction causes concerning various parameters (note that this ratio always lies between 0 and 1).

The underlying idea is to select a cause showing the deepest contradiction which offers the largest potential for a change. Moreover, such a contradiction tends to be the most apparent one and might be considered to be „unsolvable“. For these reasons it poses a good candidate for TRIZ approach. From the system evolution point of view, we assume that the criterion C4 is convenient mostly during the birth and growth phases.

When the studied system is in the phase of maturity, i.e. when many high-quality ideas were already realized and we expect a creativity level of a future solution to be lower, it could be suitable to employ the opposite criterion.

Proximity (C5) – Choose the contradiction cause which parameter seems to be closest to the switch value.

Analogously to the previous criterion, we can calculate Proximity as

$$\text{Proximity} = \left| \frac{\text{extremal value} - \text{current value}}{\text{extremal value} - \text{switch value}} \right| .$$

2.2. Combined Criteria

In practice, we need to get an overall picture and take into account several criteria. It is usually done by intuition, by guesswork or by an evaluation of ordering within particular criteria. We propose an approach based on a combination of criteria.

In order to combine the criteria, they have to meet two requirements:

● The choice of contradiction cause is determined by the highest value of criteria, i.e. criterion has to increase with significance of the cause.

● Values of criteria are normalized, i.e. their values lie between 0 and 1.

The value of a combined criterion is then obtained by a simple product of whatever number of criteria we would like to consider. In principle, it is possible to take into consideration also different weights of criteria in quite a straightforward way. However, for the sake of simplicity, we are not going to discuss such a case in this paper.

Once the RCA+ diagram involves a couple of independent causes, combining of criteria becomes almost a necessity.

Algorithm for combined criteria evaluation

1. Select which of the criteria C2-C5 you are going to employ for contradiction causes evaluation and define the way of their assessment (comparative ranking, expert estimate, measurement, etc.). Note that the criteria C4 and C5 are mutually exclusive and cannot be utilized simultaneously.

2. For every contradiction cause find values of the criterions selected in step 1.

3. If RCA+ diagram contains an effect with independent causes, assign the criterion C1 with them (via measurement, expert estimate, etc.).

4. Calculate the combined criterion for every contradiction cause, i.e. multiply corresponding values of the selected criteria and all values of C1 lying on a direct path connecting the contradiction cause and the original problem formulation. If there are two or more paths, make the calculation for all of them and add up the results.

5. Rank the contradiction causes according the values of combined criteria in descending order.

2.3. Illustrative Example

Consider a situation when a listener does not understand the speaker, from the viewpoint of an organizer during the conference. The team consisting of five members has constructed RCA+ diagram whose fragment is depicted in Figure 3. The procedure of criteria value assessment is described in the sequel.

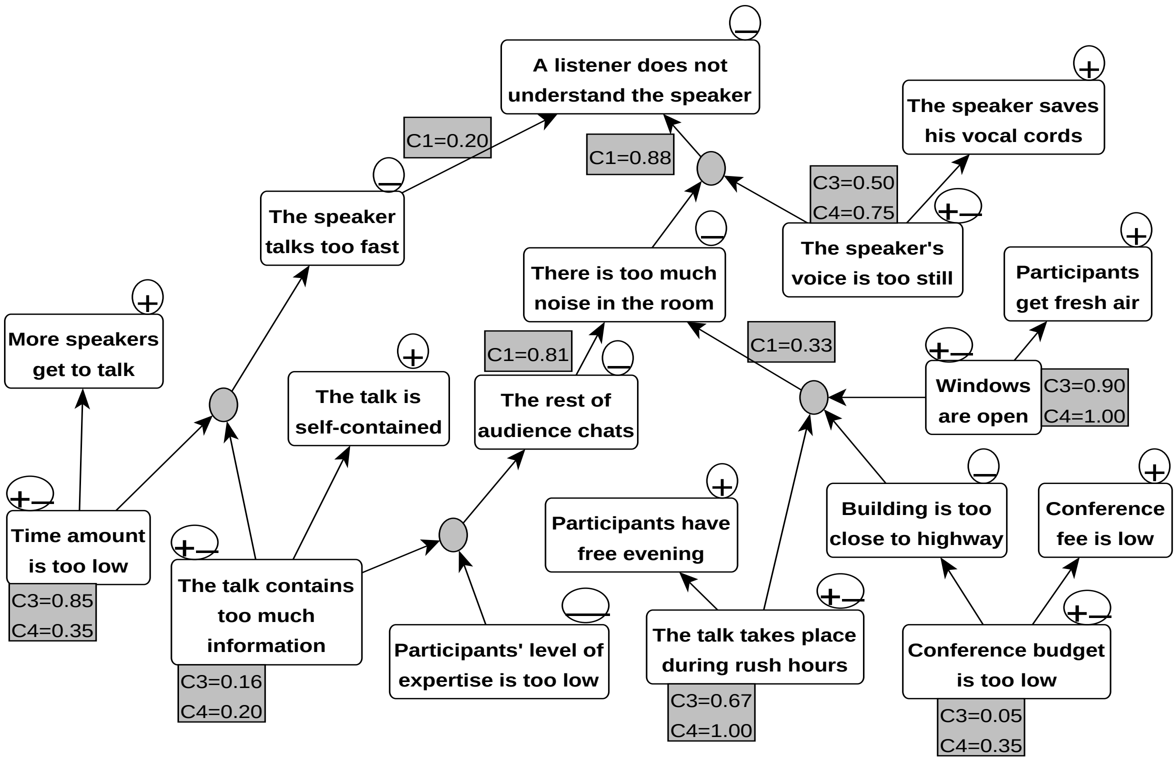


Fig. 3. Fragment of RCA+ diagram including selection criteria values

The algorithm realization

1. For an evaluation, the team has chosen the criteria Susceptibility (C3) and Extent (C4), utilization of Importance (C1) is implied by an occurrence of independent causes in the diagram. Their numerical values were specified via expert estimation followed by a broad consensus.

2. Values of C3 reflect estimates of influence that an organizer has during the conference. Regarding the criterion C4, the causes „Windows are open“ and „The talk takes place during rush hours“ we considered to be binary (i.e. C4=1), while the others were calculated from the definition of Extend supplied by estimated values of involved parameters. For instance, in the case of the cause „The speaker’s voice is too still“ the sound pressure was chosen for the key parameter with the estimated values

switch value	70 dB
extreme value	30 dB
current value	40 dB

leading to

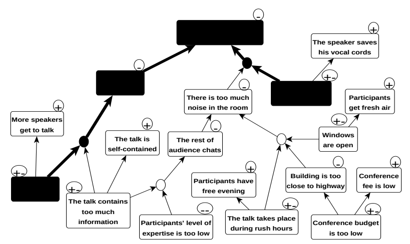
$$C4 = \left|\frac{40-70}{30-70}\right| = \frac{30}{40} = 0.75 .$$

Similarly we dispose with other contradiction causes (see Figure 3).

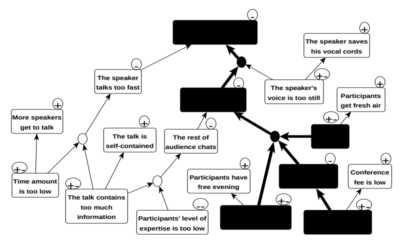
3. Values of C1 are based on personal experiences of the team members. We point out that the sum of C1 for causes corresponding to a given effect can be equal to 1 or greater, the latter case occurs when causes may occur simultaneously (see Figure 3).

4. Every contradiction cause is affected by at least one C1 criterion. From the structural point of view, the contradiction causes identified in this example can be considered of three types:

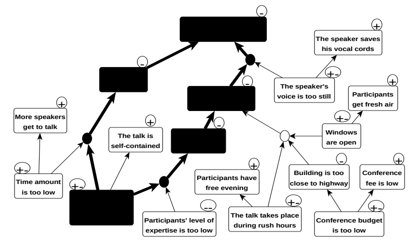
● One path, one C1 – Combined criterion is given by a product of corresponding criteria C1, C3 and C4, i.e.

Contradiction cause	Criteria values	Combined criterion	
Time amount is too low	0.20, 0.85, 0.35	0.060	
The speaker's voice is too still	0.88, 0.50, 0.75	0.330	

● One path, two C1 – Combined criterion is given by a product of corresponding criteria C3, C4 and both values of C1, i.e.

Contradiction cause	Criteria values	Combined criterion	
The talk takes place during rush hours	(0.88·0.33), 0.67, 1.00	0.195	
Conference budget is too low	(0.88·0.33), 0.05, 0.35	0.005	
Windows are open	(0.88·0.33), 0.90, 1.00	0.261	

● Two path – Combined criterion is given by a sum of combined criteria calculated for single paths, i.e.

Contradiction cause	Criteria values	Combined criterion	
The talk contains too much information	0.20, 0.16, 0.20	0.029	
	(0.88·0.81), 0.16, 0.20		

5. Finally, we sort the contradiction causes by the values of combined criterion to obtain the following priority list:

#	Contradiction cause	Combined criterion
1	The speaker's voice is too still	0.330
2	Windows are open	0.261
3	The talk takes place during rush hours	0.195
4	Time amount is too low	0.060
5	The talk contains too much information	0.029
6	Conference budget is too low	0.005

Although the idea of criteria combination is very tempting and obtained results seem to be reasonable, we can expect some obstacles during its practical use. Obviously, the key disadvantage is the necessity to provide the contradiction causes with precise numbers for each criterion. Some of them can be determined by a measurement, which consumes a significant amount of time. Thus teams mostly choose to estimate all criteria somehow, but every agreement on a particular criterion value is usually paid for with long, unproductive arguments and the resulting numbers might be always questioned. The following section suggests a way how to avoid these issues.

3. Fuzzy Extension of RCA+ Evaluation

While most of people are not able to guess the exact value of a physical quantity, such as e.g. temperature, everybody is capable of expressing his opinion whether is hot, cold etc. In this section we are going to develop this idea for RCA+ evaluation.

Our approach is based on theory of so-called fuzzy sets and fuzzy numbers. On this account, we are going to recall a few simple relevant notions which are necessary for purposes of this paper. For more general and detailed information on this exciting theory we refer to, e.g. [4,5,6].

3.1. Fuzzy Values of Criteria

Instead of trying to estimate a value of a criterion, we formulate a suitable question which characterizes an underlying idea of the criterion. For our criteria C1-C5 they could look like this:

Criterion	Possible question
C1 – Importance	If the effect occurs, how frequently is this cause responsible?
C2 – Simplicity	Do you consider the set of elements behind this cause to be simple?
C3 – Susceptibility	Are you able to influence the elements involved in this cause?
C4 – Extent	How much is the key parameter out of acceptable range?
C5 – Proximity	How close is the key parameter to the acceptable range?

Further, we choose code words for all criteria. Throughout this paper, we employ a five-degree scale, but in general we can consider an arbitrary number of levels which may differ for every criterion. Our code words are for C1 criterion „always“ – „often“ – „sometimes“ – „rarely“ – „never“ and for C2-C5 criteria „completely“ – „extensively“ – „medium“ – „slightly“ – „not at all“. Asking the team members questions corresponding to our chosen criteria, we expect to get answers such as „I can influence this just slightly“ or „I think this cause occurs often“. That is how we find our criteria fuzzy values.

Now we need to specify, what do we mean by the vague code words. Naturally, we distribute the code words equidistantly in the criterion value interval from 0 to 1. In our case it means that „never“ corresponds to 0, „rarely“ to 0.25, „sometimes“ to 0.5 etc. Regarding the other possible values of criterion, we cannot definitely decide under what code word they belong since it depends on personal opinions of team members, e.g. the value 0.3 can be interpreted as „rarely“ as well as „sometimes“. To deal with this ambiguity, fuzzy sets theory introduces so-called membership degree ($0 \leq \mu \leq 1$). We agreed that 0.25 is „rarely“, therefore 0.25 belongs to „rarely“ with membership degree 1 which means certainty. The value 0.3 is closer to „rarely“ and further from „sometimes“, hence we assign it to „rarely“ with membership degree 0.8 and at the same time to „sometimes“ with membership degree 0.2. Similarly we can dispose with every possible value of criterion. The result of this reasoning is summarized in Figure 4. The following table presents equations of boundary depicted curves.

Table 1: Membership degree profile equations for criteria values

C1	C2-C5	lower bound	upper bound
always	completely	$0.25\,\mu + 0.75$	1
often	extensively	$0.25\,\mu + 0.50$	$-0.25\,\mu + 1.00$
sometimes	medium	$0.25\,\mu + 0.25$	$-0.25\,\mu + 0.75$
rarely	slightly	$0.25\,\mu$	$-0.25\,\mu + 0.50$
never	not at all	0	$-0.25\,\mu + 0.25$

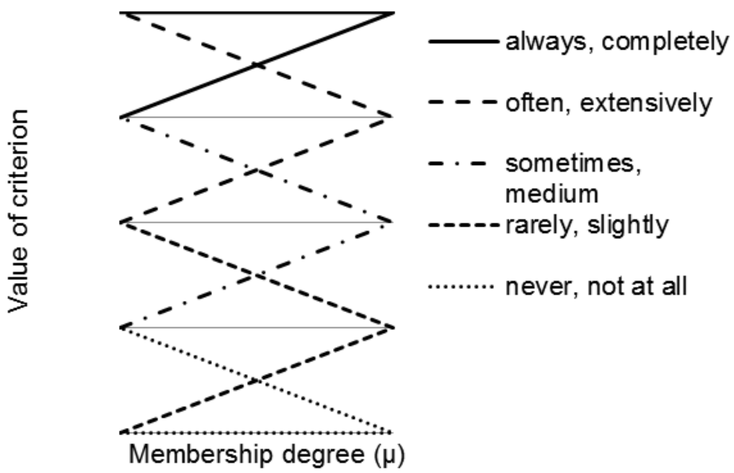


Fig. 4. Graphical representation of fuzzy values

Besides a more natural and smooth identification of criterion values, the fuzzy approach brings another benefit. There is no need to achieve an unanimous agreement on criterion values. If some team members choose „never“ and others „sometimes“, we simply consider the value „never or sometimes“ (to be more precise, we mean by that „never or rarely or sometimes“). This procedure is usually called uncertainty extension. It enables us to capture the mismatch expressed by the team and take it into consideration during the evaluation. The membership degree profile corresponding to „never or sometimes“ is simply given by the lower bound of „never“ profile and the upper bound of „sometimes“ profile (see Table 1) as depicted in Figure 5.

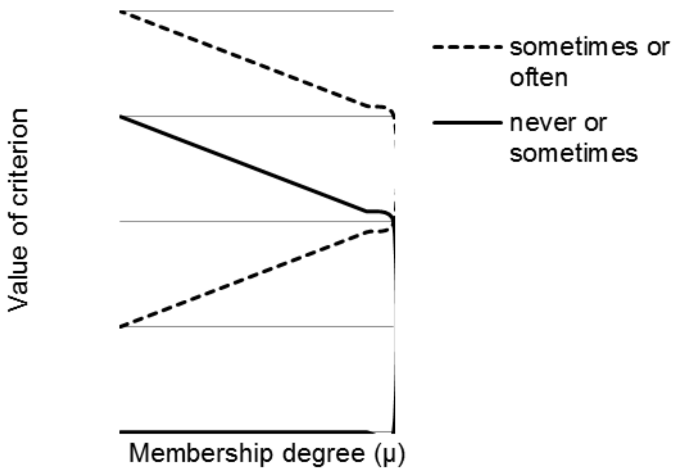


Fig. 5. Graphical representation of uncertainty extension

We note that for the sake of simplicity of calculations we have reversed the axes in graphical representations of fuzzy values. Usual convention puts value of criterion on horizontal axis and membership degree (also called membership function) on vertical one. Also, theory of fuzzy sets and fuzzy numbers admits almost arbitrary choice of the shape of membership degree profile and also it is possible to employ another ways how to combine fuzzy values. However, these techniques exceed the range of this paper and we refer to, e.g. [5,6] for more details.

3.2. Fuzzy Combined Criteria Evaluation

When we have fuzzy values of the classical criteria determined, we can move to fuzzy combined criteria. The procedure is completely the same like explained in Section 2, however we need to specify how to sum and multiply the fuzzy values. In the sequel, we only recall the necessary rules, for more detailed information, definitions and proofs see, e.g. [5,6].

The summation is needed in the special case if a contradiction cause leads to the original problem through two or more independent paths. The membership degree profile of the sum of two fuzzy terms is obtained quite straightforwardly. The resulting lower bound is given by sum of lower bounds of profiles of the involved fuzzy terms (see Table 1). The upper bound is obtained analogously. Consequenly, as depicted in Figure 6, we get

	lower bound	upper bound
never or rarely	0	$-0.25\ \mu + 0.50$
sometimes	$0.25\ \mu + 0.25$	$-0.25\ \mu + 0.75$
(never or rarely) + sometimes	$0.25\ \mu + 0.25$	$-0.50\ \mu + 1.25$

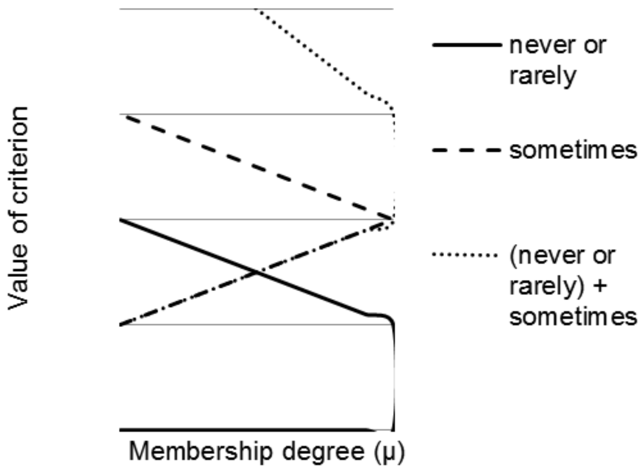


Fig. 6. Graphical representation of fuzzy summation

The multiplication, a most common operation in criteria combination, is defined in a similar manner. Bounds of the resulting profile are given by multiplication of corresponding involved lower and upper bounds, respectively (see Table 1). Consequently, we obtain a more complex membership degree profile. In particular, as illustrated in Figure 7, we get

	lower bound	upper bound
never or rarely	0	$-0.25\ \mu + 0.50$
sometimes	$0.25\ \mu + 0.25$	$-0.25\ \mu + 0.75$
(never or rarely) * sometimes	0	$0.063\ \mu^2 - 0.313\ \mu + 0.375$

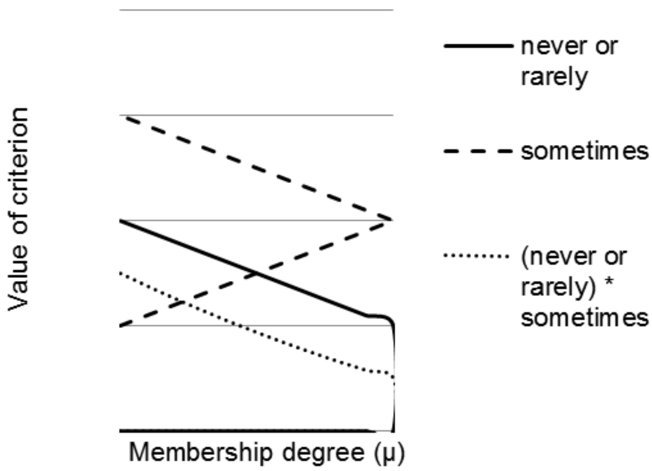


Fig. 7. Graphical representation of fuzzy multiplication

Comparison of fuzzy values

When combined criterion is evaluated for every contradiction cause, we face a question how to sort such results. In general, we want to choose the contradiction causes with the largest values of combined criteria just like in the classical non-fuzzy case. Thus we are looking for causes with the uppermost membership degree profile, in particular its lower and upper bounds. However, the fuzzy approach provides more information to consider. An interesting point is presented by the range that the particular profile occupies on vertical axis. The closer are the corresponding lower and upper boundary curves to each other (i.e. the profile occupies a lower area), the more confident the team is about the combined criterion evaluation and vice versa. This aspect can serve a supplementary sorting perspective.

In practice, we usually sort fuzzy values by an appearance of their graphical representation. To formalize this natural process, we present the following guidelines valid in most cases:

1. We sort upper bounds and lower bounds separately (if such sorting is not possible, move to the point 3). If both resulting sequences coincide, we employ the same order also on corresponding contradiction causes (see Figure 8).

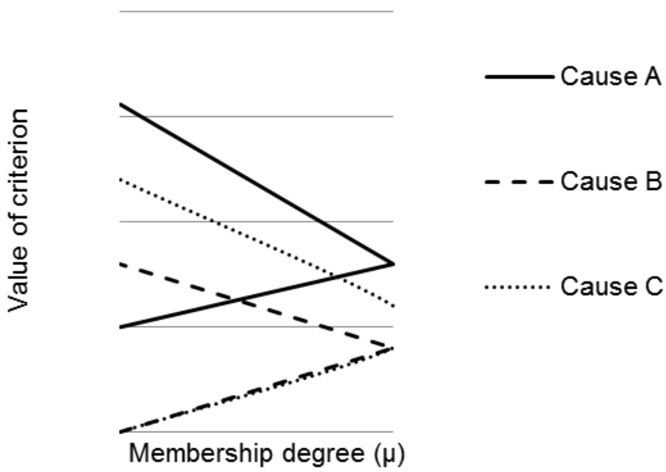


Fig. 8. A situation allowing to decide according to point 1, here B < C < A

2. If the sequences of sorted upper and lower bounds do not coincide, it means that some profile is nested in another one. Thus, we estimate (or calculate) how high the center of mass for every profile is located, and sort the results (see Figure 9).

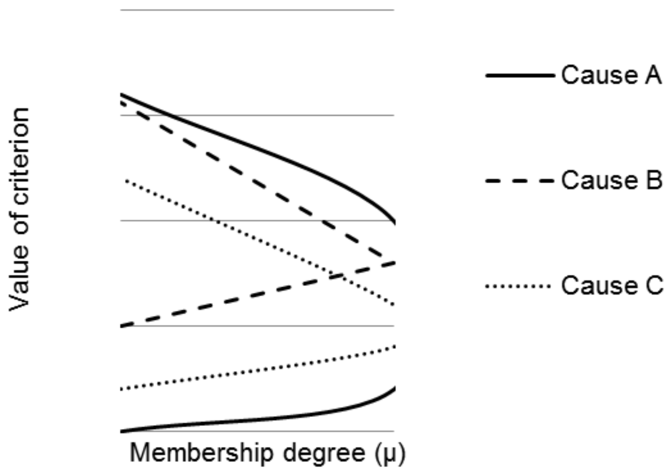


Fig. 9. A situation allowing to decide according to point 2, here we choose C < A < B

3. If upper or lower bounds intersect in a neighborhood of $\mu = 0.5$, we will not be able to sort them and the previous two points do not provide any result. Also, if centers of mass seem to be the same by estimation (or are precisely the same), we are not able to decide which contradiction cause is supposed to be selected (see Figure 10). In such cases the criterion values can be taken for equal. However, it can also be relevant to consider doubts that the team expresses via widths of range of particular profiles. The interpretation of this information depends on personal preferences of a decision-maker or on overall team disposition. Generally saying, a conservative approach perceives mostly the lower bounds, i.e. in Figure 10 the cause A would be ranked lowest. On the other side, an adventurous person would direct the attention more according to the upper bounds, i.e. in Figure 10 the cause A would be ranked highest.

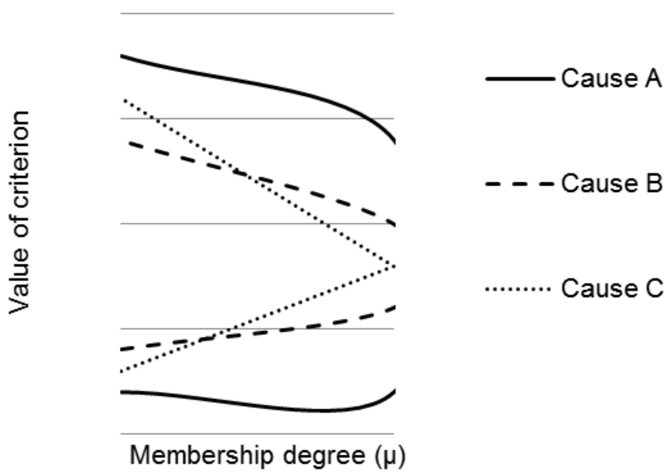


Fig. 10. A situation not providing a universal solution

We point out that the point 1 in principle coincides with the point 2 and therefore could be left out. However, we prefer to keep it since it can be more easily estimated at the first sight. Next we note that we can consider the widths of range for particular profiles also in points 1 or 2. For instance, we may penalize the cause A in Figure 9, if we think that it is suitable.

3.3. Example

We consider the same RCA+ diagram as in Subsection 2.3. supplied with fuzzy criteria values (see Figure 11). The evaluation procedure is as follows.

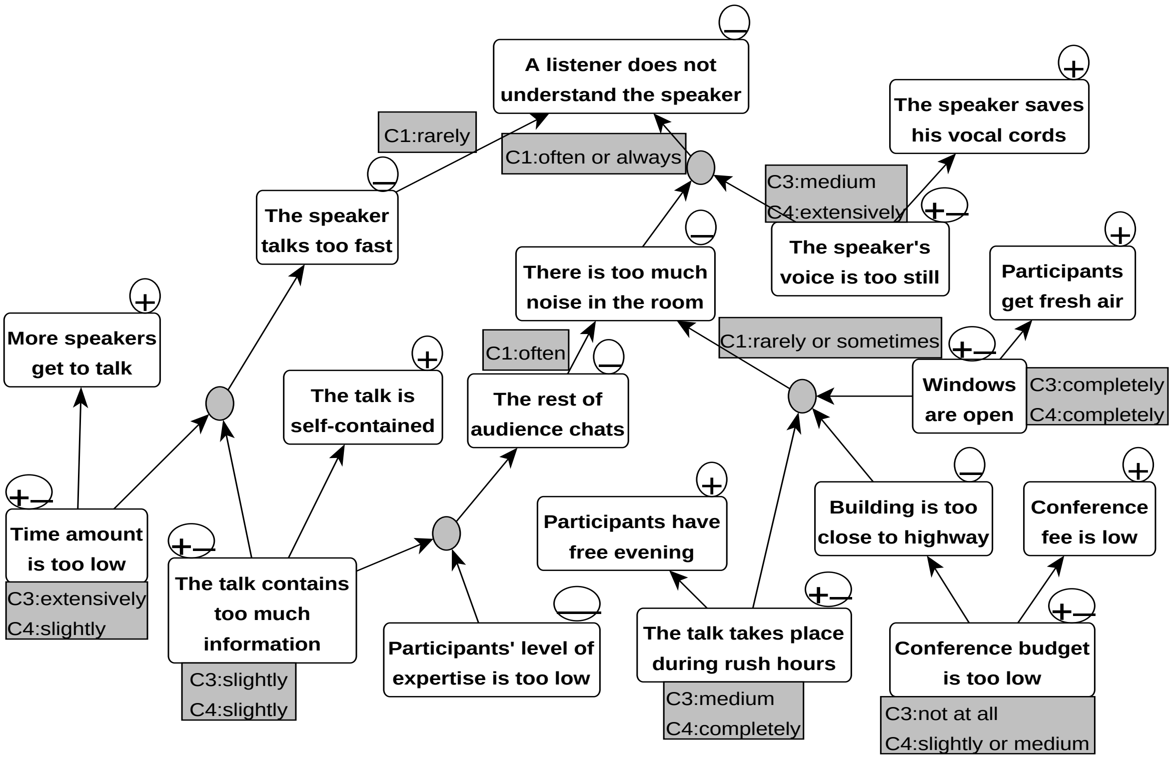


Fig. 11. Fragment of RCA+ diagram including selection criteria fuzzy values

The algorithm realization

1. The criteria remain the same, i.e. C1, C3, C4. For their assessment we utilize fuzzy values given by the code words suggested in the previous subsection.

2. Fuzzy values of C3, C4 are situated near the contradiction cause boxes (C3 in the first row, C4 in the second one). Notice that in some cases the team used fuzzy values which do not fully correspond with the former "exact" version (e.g. C3 criterion for "The talk takes place during rush hours" was marked only as "medium" despite the original value 0.67). Also, in case of C4 criterion for "Conference budget is too low" the team showed a mismatch and uncertainty extension had to be utilized.

3. Fuzzy values of C1 criterion are stated by the corresponding connections. In two cases the team did not reach a consesus and uncertainty extension had to be utilized.

4. Performing the combined criterion evaluation described in previous subsections, we get the results depicted in Figure 12.

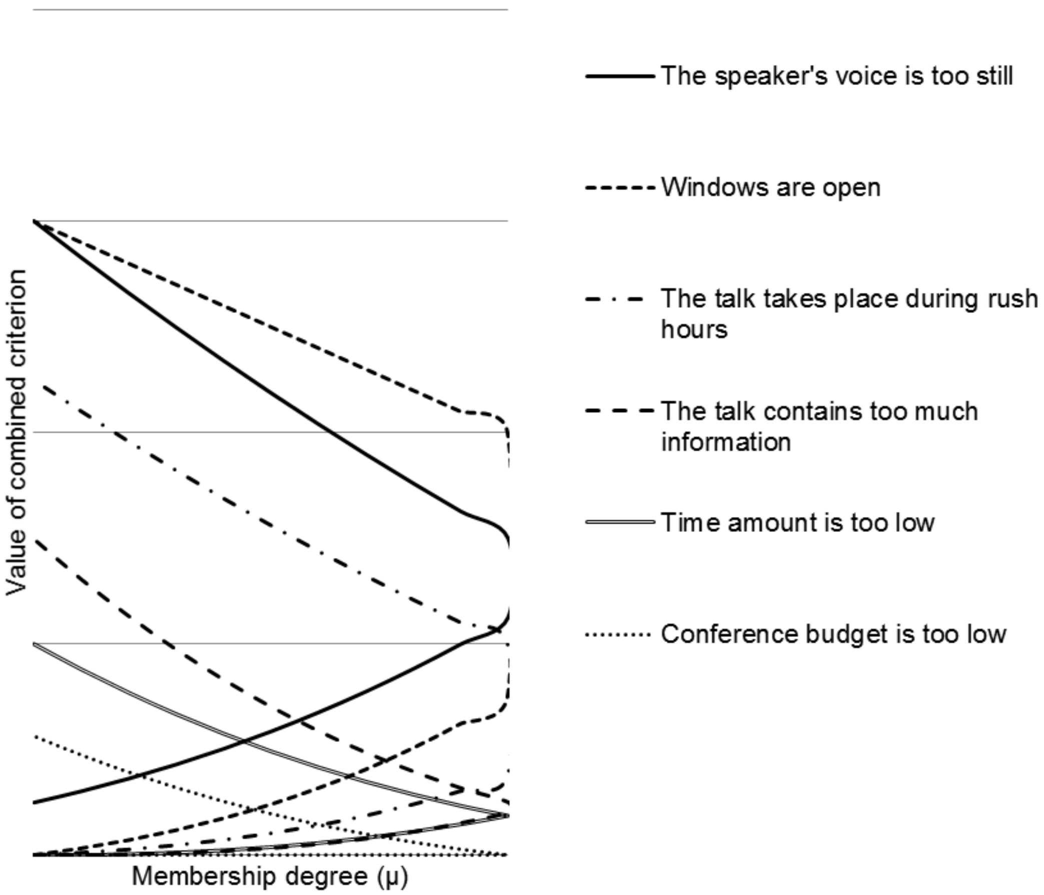


Fig. 12. Graphical representation of combined criterion values

5. Sorting of contradiction causes according to fuzzy values of a criterion is not a uniquely solvable task. Notice that the profile for “The speaker’s voice is too still“ is nested in the profile for „Windows are open“, i.e. it is not an easy-to-decide situation. If we take a closer look, we find out that the team even admits that „Windows are open“ could be a worse candidate than „The talk takes place during rush hours“. Thus, the final ranking is affected by the team temperament. The team composed from risk-takers will most likely choose the cause „Windows are open“, while more conservative group will prefer „The speaker’s voice is too still“.

#	Contradiction cause	Profile’s center of mass
1	The speaker’s voice is too still	0.363
	Windows are open	0.350
3	The talk takes place during rush hours	0.224
4	The talk contains too much information	0.124
5	Time amount is too low	0.087
6	Conference budget is too low	0.043

In this paper we follow the primary starting comparison technique based on sorting of profiles’ centers of mass. We point out that the centers of mass belonging to the nested contradiction causes “The speaker’s voice is too still” and “Windows are open” are quite close. As discussed above, the profiles reveal many relevant information, not just the position represented by the center of mass, but also e.g. the shape, range (i.e. level of agreement). On this account, we list these two contradiction causes at the shared first place and leave the final decision up to the reader’s personal preference.

4. Discussion and Conclusion

We have proposed an approach for evaluation and selection of contradiction causes using linguistic statements (e.g. “rarely”, “medium” etc.) instead of numerical values. Also, we have suggested two new simple criteria (Extent and Proximity) which can be convenient in many situations.

Our method is based on the idea of combined criteria evaluation and on basic notions of fuzzy sets and numbers theory. Its key advantage is very fast and easy criteria assessment, since due to the use of vague terms, team members are not forced to reach a full consensus for every single value of criterion. Moreover, the differences in opinions are valuable supplement for the final ranking (although the opinions should not diverge too much, otherwise the results would suffer from too much uncertainty). Consequently, such assessment can be performed directly during or immediately after the RCA+ diagram construction. Next important feature of this approach is its resistance against result questioning. The vagueness of input data is not only admitted but even taken into account and employed as one of decision sources (see subsections 3.2 and 3.3). As a disadvantage of this method we could consider a suitability of computer involvement during the evaluation of linguistic combined criteria. However, the algorithm can be easily realized, e.g. via elementary MS Excel functions.

We believe that the proposed approach can serve as a valuable tool for evaluation of large RCA+ diagrams as well as other decision-making situations. It considers every item (contradiction cause) individually and therefore its computational complexity increases linearly (e.g. the comparative ranking technique shows quadratic computational complexity growth).

References

1. Reinders A., Diehl J.C., Brezet H. The Power of Design: Product Innovation in Sustainable Energy Technologies. John Wiley & Sons, Inc. 2013.

2. Souchkov V. “Root conflict analysis (RCA+): Structuring and visualization of contradictions”. Proceedings of “ETRIA TRIZ Future 2005 Conference”, Graz, 2005.

3. Souchkov V. Guide to TRIZ Techniques for Technology and Engineering: Course Guide. ICG T&C. 2012.

4. Siler W., Buckley J.J. Fuzzy Expert Systems and Fuzzy Reasoning. John Wiley & Sons, Inc. 2005.

5. Zadeh L.A. et al. Fuzzy Sets, Fuzzy Logic, Fuzzy Systems. World Scientific Press. 1996.

6. Zimmermann H.-J. Fuzzy Set Theory and Its Applications. Springer. 2001.

Author (co-author) to contact: Tomas Kisela, tomas.kisela@scacp.cz

TRIZfest 2014

RESOLUTION OF PHYSICAL CONTRADICTION BY TRANSITION TO THE MICRO LEVEL: EXPERIENCES AND RECOMMENDATIONS

Sergey Logvinov, Pavel Jirman[a]

[a]*Technical University of Liberec, Liberec, 460 01*

Abstract

The method of transition to the micro-level is an effective way to resolve physical contradictions. This is especially true in case of the application of "Smart Materials", which have been actively used for the last 10-15 years.

On the other hand, the analytical and solving tools of modern TRIZ are lacking a specific algotithm which:

- allows to clearly identify situations in which the use of the transition to the micro level is advisable
- gives advice for such a transition

A project at Technical University of Liberec focuses on methods of systematic creativity on micro level and deals with this objective: The development of guidelines for the application of transition to the micro-level. Some results of this work will be presented in this article.

Key words: TRIZ, ARIZ, contradiction, transition to micro level, searching of resources, Function Analysis,

1. What is a transition to micro level? Background/History of question

The concept of "transition to micro level" is used in the three tools of TRIZ: in the Laws of Technical Systems Evolution, in the different versions of ARIZ and also in the System of Standards. We briefly discuss the features/ particularities of using this concept in different tools.

Apparently, the concept of the transition to micro level first appeared in the mid-70s in the system of the Laws of Technical Systems Evolution formulated by G.S.Altshuller [1]. The Law of Transition From Macro to Micro Level was included in the group "Dynamics"which had the following formulation: "Development of the working tools of a system first proceeds at macro, and then at micro level."

The transition to micro level is mentioned also in the following versions of the Laws:

For example, in the version of B.Zlotin and A.Zusman [2], we notice that the transition to micro level is mentioned as a separate law (6. transition to micro level and the use of the fields), and as a way to implement the other laws (5. increase of dynamics and controllability of Technical system: one way of implementation is transition to the subsystem (changing on a micro level).

At the same time, in the version of S.Litvin and A.Lubomirski [3], the transition to the micro level is not regarded as a separate law, but as a trend, implementing the laws increasing controllability and dynamics.

About the same time, the concept of transition to micro level also appears in ARIZ..

Firstly, an implicit reference to the use of this tool is made in ARIZ-77: "4. Elimination of the physical contradictions ... 4.1. g) way of changing the structure: the particles in the separated zone of the element are endowed with existing properties and the entire selected zone as a whole is endowed with the required (conflict) property. "Formulation of the physical contradiction at micro level is introduced in ARIZ-82A in step 3.8: "the particles of a substance in the operational zone should (...) to provide (...) and should (indicating the opposite physical condition of small particles of substance ...) to provide (specify the required opposite macro state). "This formulation is repeated practically in ARIZ-85C (step 3.4). There are two important notes to this step:

"Note 27. There is no need to specify the concept of "particles" in step 3.4. yet. These may be, for example, domains, molecules, ions, etc.
Note 28. Particles can be: a) just particles of substance, b) particles of substance in combination with a certain field and (more rarely) c) "particles of field"."

This means that the used concept of "particle" is defined very broadly, without direct specification to the nature and size of the particles. Furthermore, the transition to micro level includes widespread use of fields.

And finally, the System of Standards directly includes the Standard 3.2.1 "Transition to micro-level" formulation which is practically identical to the formulation of one of the principles for physical contradictions elimination in ARIZ-85C (Table 2 "Eliminating of physical contradictions"). However, there is a substantial difference: Transfer to micro level is understood quite narrowly: "the transition to micro level, means that the system or it's part is replaced by a substance capable of interacting with the field to perform the requested action."

As become obvious now, the concept of transition to micro level has quite significant differences in the different tools of TRIZ. Furthermore, specific algorithm is missing which would perform this transition. The particular aim of our work is an attempt to formulate such an algorithm of transition to the micro level.

We have formulated the basic questions that we must ask ourselves in order to continue:

- Is the transition to micro-level a trend of evolution or an instrument to eliminate contradictions?
- What is meant by "micro-level?" Is this the level of substance properties or can larger elements (in the terms of the characteristic size or system-level of analysed element) also be considered ?
- Is it necessary to consider the involvement of fields?
- In what situations is it advisable to apply the transition to micro level?

2. Transition to micro level and resources in Technical System

The most logical approach to the concept of "transition to micro-level" is described in the System of Standards: There are two ways of transition to fundamentally new systems: transition to a super-system ("way up", the standards of Class 3.1) and transition to the use of "lower" subsystems ("way down", Class 3.2). This approach implies that the transition to micro level is done with a quite specific purpose: to find new resources to solve problems. **In this way, transition to micro level (as well as the transition to super-system) is neither a**

trend, nor a goal but a method of searching resources. A similar approach has been used in different versions of ARIZ. For example, in ARIZ-91, the physical contradiction on the micro level is formulated with respect to the particles of the main resource.

To improve the instrumentality, it is advisable to escape from the definition of "lower subsystem" and to understand it as a transition to micro-level search of solutions on any level of (sub-) subsystem. In this case appears as a single user-friendly approach, without any formal ties to the characteristic size.On the one hand this appears very convenient. We do not have to answer any question such as "Is particle size 1 mm the micro-level or not?" On the other hand, obviously macroscopic objects may fall into the concept of micro level as well. This may contradict common logic, but it helps to overcome psychological inertia.

Next question: inclusion of the considered fields. Without doubt, the fields should also be taken into consideration. This reduces the number of analytical tools we may choose from to address the transition to the micro level. Since the transition to the micro level is a special case, the development of a specific tool is not very practical. It is therefor reasonable to look for an existing widely used analytical tool. From the point of view of the authors, the most appropriate analytical tool is Functional Analysis (FA) for the following reasons:

- FA can effectively analyze various system levels of Technical Systems (TS). For the transition to the micro-level, especially analysis of (sub-) subsystems is required.
- FA permits to formulate contradictions on any system level, including the micro level
- FA can correctly include fields
- There has been a common trend to integrate analytical TRIZ tools around FA for the last 10 years. It is reasonable to integrate tools for transition to micro-level into FA as well.

Finally: when is it appropriate to apply the transition to the micro level? In the view of the definition given above, the answer is obvious: **the transition to the micro level is appropriate in cases when resources needed to eliminate the contradictions at the current system-level of the considered problem are missing**, and the transition to a super-system is prohibited by constraints of the tasks.

Thus, for making the transition to micro level we propose to:

- Find resources needed to solve the problem in the (sub-) subsystems of the TS
- Define the concept of "micro level" not by geometric scale, but by the scale of system levels of the TS
- Use the potential of FA to identify resources in the subsystems of Technical System, including correct inclusion of fields

3. Case study of transition to micro level

We applied the proposed approach to a case study. A glass plate was chosen as the object of analysis and insufficient bending strength as the target defect (the example was chosen because of its well-known solutions) - see Fig. 1.

Fig. 1 Glass plate with insufficient bending strength

The assumed boundary conditions are: it is not allowed to increase the weight or significantly change the composition of the glass.

For the analysis of possibilities of transition to micro-level, we will use a table (two-dimensional array). In the cells of the table we will propose the solutions. The solutions will be ordered in the table according to several parameters "key problem / resource." We will organize the key problems (including identified contradictions) in the first column (vertical) according to the system level which the problem is formulated for. The lower the rank of system-level, the lower is the problem. We will organize the used solutions in the first row (horizontal). The lower the system-level of the resource used to solve the problem, the farther on the right it is located in the table. The table presented is in fact the system operator with the two axes of system level of problem and system level of solutions.

Table 1

The resulting table of a glass plate problem

System level Key problems	1 Macro level - Plate parameters	2 Micro level 1 - Parameters of plate layers	3 Micro level 2 - Parameters of areas with Griffith cracks	4 Micro level 3 - Composition and structure of glass at molecule size
1 Macro level (plate). How to increase strength of plate	1.1 Change shape of plate			
2 Micro level 1 (layer of plate). How to create compressive stresses in outer layers of plate		2.2 Hardening		2.4 ion-exchange
3 Micro level 2 (outer layer - areas with Griffith cracks / without cracks). How to reduce / delete effect of Griffith cracks?		3.2 Etching of outer layer and various methods of polishing	3.3 "Healing/ smoothing" of defective areas	

4 Micro level 3 (several interatomic distances). How to increase strength of micro domains?				4.4 Increasing Strength by change of micro structure in magnetic field

Note. Unfortunately, the scope of this article does not allow to show the corresponding fragments of FA models.

3.1.Commentary on the table

Solution 1.1

The key problem is formulated at macro level: how to increase the strength of the glass plate. At the system level, the only one available resource is the shape of the plate (assuming that the restrictions are not to change weight and composition of the plate). The classical solution is to change the shape (ribs, corrugations, etc.). However, this solution is not always applicable.

Solutions 2.2 and 2.4

In this case, the key problem is formulated at the subsystem level: layers of the glass plate. This level is not the micro level in the traditional sense. However, in the framework of the proposed logic, we have to consider this level, too. The key problem is resolved by creating compressive stresses in the outer layers of the plate. Creation of compressive forces can be done by the resources at any system level.

When we use resources of the same system-level (the properties of the outer layer), we obtain the solution 2.2 - tempering. However, the same effect can be also obtained by using ion-exchange (solution 2.4). In this case, the resource is located two system levels below- the glass composition and the structure has standard order of distances.

Solutions 3.2 and 3.3

The key problem is formulated even one system level below: on elements (particles) which are not considered to be layers of glass, but microscopic areas containing / or not containing so called Griffith cracks. There are two solutions to this problem. The first solution are attempts to "heal/ smooth" defective areas (Solution 3.3). Here, the system levels of key problem and used resources coincide. Solution 3.2 is very interesting : the key problem is solved by using a resource on a higher system level (the removed layer both defective and non defective areas). In fact, the problem is solved by trimming of the problem element (area with Griffith cracks) together with an element of a higher system level (the outer layer of the plate)

Solution 4.4

This solution can be considered as a classical solution of "transition to the micro level". The key problem is formulated at the level of a few interatomic distances and solved by processing in a magnetic field, which changes the structure.

4. Conclusions

To increase the instrumentality for performing the transition to the micro level we recommend the following algorithm:

- Step 1: Perform Functional Analysis on as many system levels as possible, down to the level of interatomic distances. Whenever possible, formulate the key problems as functional contradictions.
- Step 2: Sort identified key problems in the first column of the table according to the system level, with respect to the formulated key problem
- Step 3: Introduce formulations of identified system levels in the first line of the table
- Step 4: Identify available resources on each system level. Try to solve the identified key problems making use of resources.

Note: In solutions that are on the diagonal of the table, the system levels of problem and resource coincide. In solutions which are above the diagonal, the system level of the resource is below the system level of the problem - these solutions correspond to the classic concept of "transition to micro level." Solutions lying below the diagonal use deep trimming which means that the problematic element is trimmed together with the element of higher system level.

Advantage of the algorithm are:

- Systematic procedure for the formulation of the key problems of different system levels
- Systematic procedure for the identification of resources on different system levels
- Means of finding non-obvious pairs of "key problem / resource " during the analysis of each cell in the table
- Using the tools of elimination of contradictions on the micro level does not differ from their use on the macro level. The main difference is the use of resource located on lower levels. The presented table permits to implement a systematic method to identify resources on different system levels to solve problems and contradictions.

The disadvantage of the algorithm lies in increased complexity of the analysis associated with the need to perform Functional Analysis on several system levels. However, the increase in complexity is compensated by the possibility of obtaining a "field of solutions," instead of just a single acceptable one.

References

1. Альтшуллер Г.С. О законах развития технических систем. – Баку, 20.01.1977

2. Злотин Б.Л., Зусман А.В. Законы развития и прогнозирование технических систем: Методические рекомендации. - Кишинев: Картя Молдовеняскэ, 1989.-114 с.

3. http://www.metodolog.ru/00767/00767.html

Author (co-author) to contact: Pavel Jirman, jirman@glass.cz

TRIZfest 2014

Small Turbojet Engine Innovation and TRIZ Instruments

Zdeněk Katolický[a], Bohuslav Bušov[b], Milada Bartlová[c]

[a]Air Division of PBS, Velká Bíteš, 595 01, Czech Republic

[b]Brno University of Technology, Brno, 616 00, Czech Republic

[c]Brno University of Technology, Brno, 616 00, Czech Republic

Abstract

Comparing to concurrent small turbojet engines this Czech design has several important parametrical advantages: weight, power, reliability, cost, etc. Innovations were obtained by creative/inventive solutions in which several instruments TRIZ were used objectively.

In this article, the turbojet engine is presented as a case study: As an example for teaching the TRIZ methodology to students and engineers and as a solution of turbojet engine for small and unmanned air vehicles.

Keywords: turbojet engine, evaluation, competition, TRIZ

1. Small turbojet engines

Both small civil and armed unmanned air vehicles are being used more and more. Small turbojet engines are also used to propel such air vehicles. Thrust/weight ratio is a critical parameter representing the main function of the turbojet engines. Engine service life, engine size, its controllability and ability to generate repeated start during flight are other significant parameters. All parameters important for users as well as for assessment of novelty and competitiveness have been improved during the development of the small turbojet engines TJ100 – TJ100S-125 [6].

1.1. Turbojet engines TJ100 and TJ100S-125

Engines TJ100 have been developed since 2002. Novelty by the law is protected by Czech utility model [2] and Chinese patent [3]. From the customer's point of view the engine novelty lies especially in parameters "small size" and "small engine weight".

The Czech utility model [4] is applied to the innovative engine TJ100S-125. Utility model fundament consists of new technology of coating of integrally cast turbine parts with aluminum by new CVD method "Out of pack" that extends significantly the working life of main engine parts.

Another novelty of TJ100S-125 engine lies in the use of the Czech patent [5]. The patent fundament consists of the new system of regulation of fuel supply to the combustion chamber.

In comparison to the predecessor TJ100, two latest novelties [4, 5] of the TJ100S-125 turbojet engine can be characterized by improvement of next critical parameters perceived by customers.

Table 1. Main improvements of TJ100S-125 engine

Parametr	Unit	Original - TJ100	After innovation - TJ100S 125
Thrust	/N/	1 100	1 250
Operating lifetime	/hod/	50	200

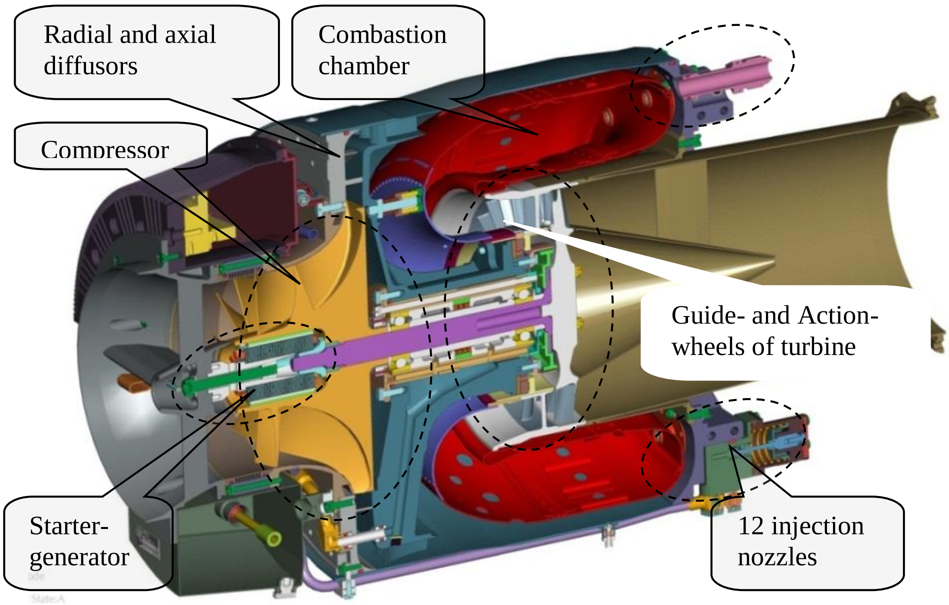


Fig. 1. Small turbojet engine TJ100S-125 [6].

The innovative engine TJ100S-125 with the thrust of 1250 N several substantial improvements achieved.

The turbojet engine thrust was increased by the following partial innovation: - new compressor stage with higher air compression efficiency; - new type of combustion chamber with higher combustion efficiency and lower smoke number; - new profiling of turbine stage with higher efficiency; - the fuel pump efficiency increase of 15% (increase of fuel supply with unchanged power input).

The turbine working life was increased several times using the new developed technology of aluminum coating of guide-wheel and action wheel.

The turbine engine controllability was improved including the start ability increasing up to the altitude of 6000 m through in principle new controller of bypass nozzle fuel [5] and improved control unit software.

The above mentioned new design solutions of several components, higher thrust, better controllability and substantially increased working life of the turbojet engine place the product in the level of qualitatively new solution [1, 7].

1.2. The difference of main function and parameters of TJ100S-125 engine from the competition

In the power category of comparable turbojet engines with the thrust of 1000 – 1500 N, there are significant competitors: SALUT (Russia), Williams Int. (USA), Microturbo (France).

Compared to competition, the TJ100S-125 engine has the following advantages:

- Maximum thrust at the lowest weight. The thrust-to-weight ratio is up to two times better than the competition.

Table 2. Comparison of TJ100S-125 engine from the competition

Engine producer	Microturbo	Williams Int.	SALUT	PBS V. Bíteš
Engine type	TRS 18	WJ 24-8	MD 120	TJ100S-125
Max. thrust /N/	1 150	1 089	1 177	1 250
Engine speed 100% 1/min/	47 200	52 000	52 000	59 000
Compression	?	?	(7,2)	5,2
SFConsumption /kg/daNh/	1,2	1,2	(1,04)	1,15
Weight /kg/	37,5	22,68	35	19,6
Max. diameter /mm/	303 x 350	292 x 383	265 x 300	ф 272
Length without exhaust /mm/	600	501	750	488
Control unit	External analog	Hydro-mechanical	External analog	Integr. FADEC +convertor 1 kW
Manner of start	Electrical	By air	By air / pyrocartidge	Electrical
Altitude /m/	10 000	12 000	10 000	10 000
Time to general repair /h/	?	25	15	200
Lubricating system	Autonomous	Lossy	By fuel	Autonomous
Thrust / weight ratio /daN/kg	3,07	4,80	3,36	6,38

- The smallest frontal section. All engine instruments including fixation spots don’t exceed the outer envelope diameter of 272 mm.

- Integrated electronic control system of FADEC type (Full Authority Digital Electronics Control) including a convertor DC-DC that in cooperation with starter-generator ensures reliable start by the on-board power adapter up to the altitude of 6000 m and the power supply of 1 kW to the board net throughout the operating speed range.

- Autonomous oil system with gear pump, filters, centrifuge oil-air, fuel-oil heat exchanger, and cooler air-oil tanks. The system is fully acrobatic; it allows the engine to run at minimum 10 hours on a single oil charge as well as long-life rotor.

- Digital control system that provides fully automatic engine start process, setting and checking the desired mode of engine work, thrust correction according to the intake air temperature and automatic process of stopping the engine. The motor control is possible by analog signal or via the CAN Aerospace bus type. Built-in sensors and programmed protection system allow safe operation of the flight.

- All electric drives including starter-generator are brushless and maintenance free.

- Fuel nozzles with a so-called bypass that in connection with bypass controller enable wide range of fuel delivery with high quality of spray. It made possible to achieve reliable starts in flight and a large range of engine speeds from 50% to 100% (130 N - 1 250 N).

1.3. Differentness of auxiliary functions of TJ100S-125 from competition

A unique design with a built-in starter-generator in the compressor body allows the user smooth engine start in the range of ambient temperatures from –40°C to +50°C by means of 28V battery, current consumption up to 100 A.

Competitive engines started by air require ground equipment including compressor and pressure vessels, which increases the cost by up to 30% of engine price. Weight, total mobility and flexibility of such a solution are low.

Unique opportunity of in-flight electric start allows to restart the engine either by instruction of the pilot or automatically based on the selected program. Experience confirms the need for this functionality, which reduces the occasion of total loss of the flying device.

Engine has the air take-off behind the compressor, which allows the user: - to pressurize fuel tanks; - to heat or to blow-off board systems; - to inflate landing bags.

Digital control system enables to program the engine functions according to customer needs, and to record all error messages for the last two hours of engine operation. Using the monitoring software can easily trace any defects.

A control system monitors the real engine operation and by the algorithm evaluates the residual source in hours and cycles.

A control system transmits via bus the engine operation data (speed, temperature, voltage, current), and allows control of either by the pilot or remote-control of flying device.

Table 3. List of existing users (15.5.2014)

COUNTRY	COMPANY OR INSTITUTIONS	Number of sold engines
United Arab Emirates	ATS	220
China	3 R&D, 2 Universities, 2 Companies	126
Russia	SOKOL, Rosoboronexport	82
USA	SONEX, Carlton, BD, Micro...	9
Špain	INTA	15
Saudi Arabia	Research Institute	6
Čzech Republic	VZLÚ	3
Denmark	Xiroco	1
Italy		1
SUMA		463

All additional materials published by PBS Velká Bíteš [6] will be accessible for conference.

Fig. 2. Civil and military application of TJ100 [6].

2. Where and how TRIZ was used

2.1. Contradictions and principles of their solutions in TJ100 turbojet engine

2.1.1. One inside the other

Reducing the volume (volume, 7th row in Altschuller table) of turbojet engine by small frontal area (electric machine located outside in front of the compressor on a common shaft) leads to the extension of the built lenght (length, 3th column in Altshuller table) and total weight (1th column). Possible formulations of technical contradictions (TC):

TC1: volume 7/3 lenght – recommended heuristic principles (HP): **1**, **7**, 35, **4** and

TC2: volume 7/1 weight – recommended heuristic principles (HP): **2**, 26, 29, **40**.

Whereas the TC1 and TC2 formulations are only verbal models of the problem being dealt with, visual models of the same problem/contradictions being solved are more illustrative. They can be found in the right upper part of Fig. 3 visualising the complete problem situation through the RCA+ built chart [7].

Recommended principles "Segmentation" (HP1), "One inside the other" (HP7) and "Extraction of harmful property" (HP2) could be imaginative and were objectively applied. One object (starter-generator) was built inside the other (compressor), and so were "extracted" worsening length/weight. In new engine solution TJ100 both built-up volume, smaller frontal area and reducing the length were achieved, as well as the weight of the engine was reduced.

2.1.2. Several times vice versa

However, to reduce the overall built-up volume (7) by integration of starter-generator inside the turbojet engine (one inside the other), as mentioned above, in a conventional way (powered static stator and rotating rotor with permanent magnets), leads to extinction of the frontal area (5), extinction harmful action of centrifugal force on the rotor magnets (30), extinction of the air gap between rotor and stator, extension of inner diameter (3) and weight of the stator and compressor impeller, which complicates (33) the use of such a construction. Possible formulations of technical contradictions (TC):

TC3: volume 7/5 area: HP: 1, **7**, **4**, **17**

TC4: volume 7/30 harmful effects on magnets: HP: **22**, 21, 27, 35

TC5: volume 7/3 diameter: HP: 1, **7**, **4**, 35

TC6: vume 7/33 complication: HP: 15, **13**, 30, 12

Again, it is useful to supplement verbal problem models (TC3-TC6), namely by visual models of partial problems being solved. Visible map of these TC3-TC6 contradictions within the framework of the whole problem situation can be found below (Fig. 3, right side).

Principles: introduce "Asymmetry" (HP4), "One inside the other" (HP7), "Converting harm into benefit" (HP22) "Inversion" (HP13), could be inspirational and were objectively applied.

In the new solution of TJ100, the stator is placed inside the rotor, which is built-up in the compressor impeller. Permanent magnets are not on the surface of the rotor, but conversely on the internal diameter of the outer rotor. Magnets are not centrifuged as usual from the rotor surface, but conversely are pushed to the internal surface of the outer rotor. Objectively and multiple times used heuristic principles "inversion", "asymmetry" and "converting harm into benefit" led to the creation of TJ100 engine with small dimensions, low weight and therefore to the higher indicator of design quality – thrust/weight.

New solution of very compact engine TJ100 can be evaluated in terms of TRIZ such as:

- Overcoming several contradictions (TC1-6) by combinations of several heuristic principles;

- Effective merge of two alternative systems (compressor, electric machine), originally as a "tandem" up to the level of fusion - "one inside the other" [9];

- Partially "trimmed" electric machine, now built-up inside the compressor [9].

However, TJ100 engine has been further improved. But by raising the engine thrust now.

Problem situation with numerous contradictions can be visualized when chain of causes is composed [8], causes leading to the desired parameter thrust/weight in this case. Parameter thrust/weight very well represents the achieved quality of turbojet engine design (Fig. 3).

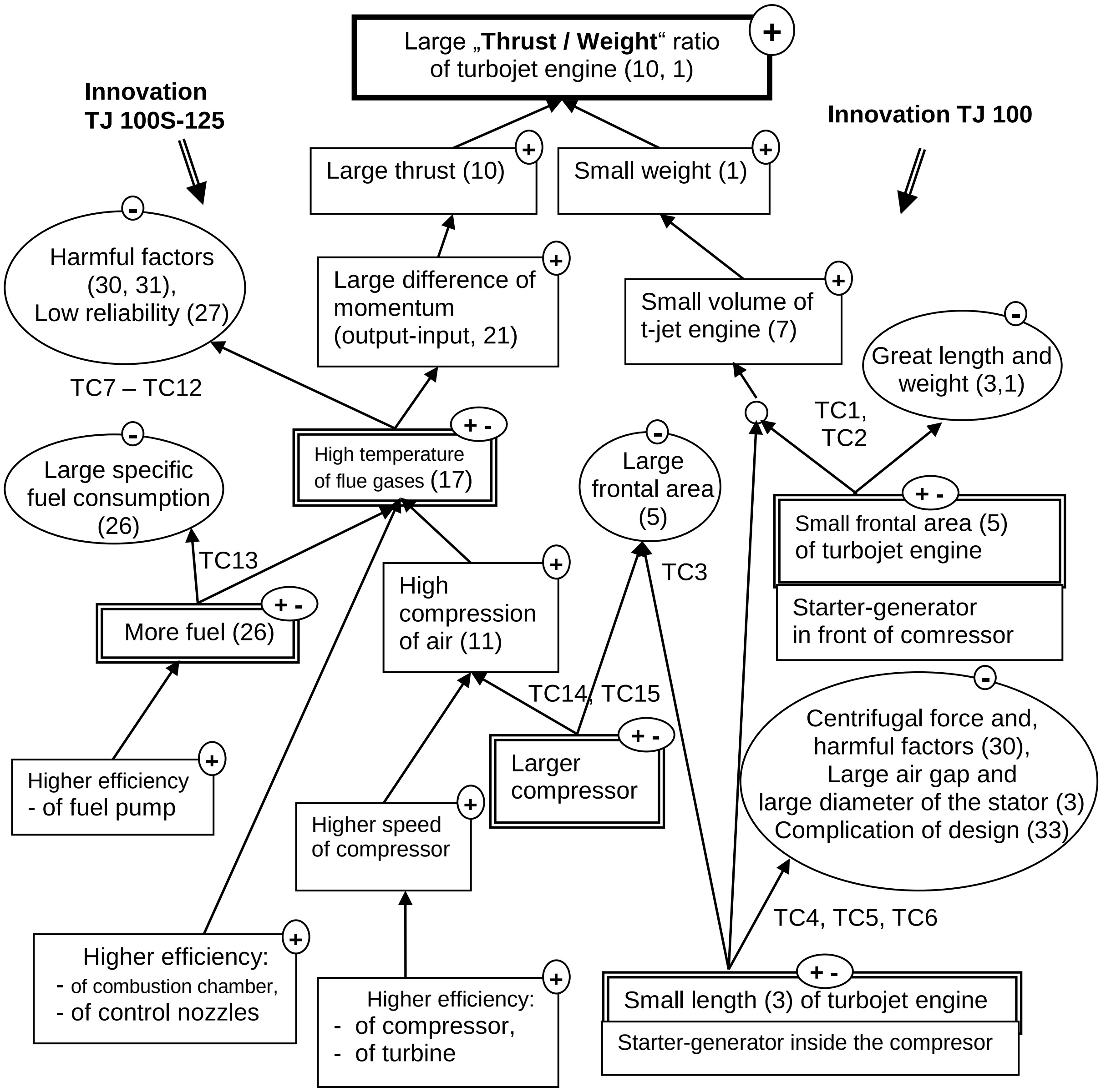


Fig. 3. Root Cause Analysis (RCA+) – the map visualising technical and physical contradictions solved in frame of TJ100 (right side) and TJ100S-125 (left side) turbojet engines innovations.

2.2. Innovative engine TJ100S-125

Engine TJ100 (2002) was further innovated up to the variant TJ100S-125 (2012), which was awarded the Gold Medal at the International Engineering Fair, Brno (2013).

In the new engine TJ100S-125 the working life and the reliability of exposed engine components are increased, especially of turbine guide-wheel and action-wheel [4].

In the new engine TJ100S-125 higher thrust, better controllability and start ability are achieved at a lower specific fuel consumption [5].

Such improvements, namely thrust and reliability, are usually contradictional, either one or the other. How the improvements were achieved?

2.2.1 Thrust versus engine reliability of TJ100S-125

Increase of engine power or thrust (21 or 10) by higher exhaust gas temperature leads to higher oxidation (harmful factors, 30) and shortening of the working life (31) and reducing the reliability (27) of exposed components: combustion chamber, guide-wheel and action-wheel. Variants of contradictions: TC7: power 21/30 harmful factors: HP: 19, 22, **31**, **2**

TC8: power 21/31 harmful factors: HP: 26, **10**, 34

TC9: power 21/27 reliability: HP: 19, **24**, 26, 31

TC10: force 10/30 harmful factors: HP: 1, **35**, **40**, 18

TC11: force 10/31 harmful factors: HP: 13, **3**, 36, **24**

TC12: force 10/27 reliability: HP: **3**, 35, 13, 21

Heuristic principles: Porous materials (HP31), Extraction of harmful property (HP2), Preliminary action (HP10), Establish a mediator (HP24), Segmentation (HP1), Change of physical-chemical parameters (HP35), Composite (HP40), Phase transitions (HP36), Local quality (HP3), could be inspirational and several were objectively applied.

Increase of engine power or thrust was achieved by higher flue gas temperature but without shortening of service life and reducing the reliability, thanks to newly developed technology of coating the exposed parts [4]. See Fig. 3, left side.

2.2.2 Temperature versus fuel consumption of TJ100S-125 engine

Increase of flue gas temperature (17) by greater quantity of fuel leads to undesirably high specific fuel consumption (26). Possible formulation of technical contradiction:

TC13: temperature 17/26 fuel quantity: HP: **3**, **17**, 30, 39

Heuristic principles: Local quality (HP3) and Shift to another dimension (HP17) could be inspirational and were objectively applied.

Higher temperature was achieved by greater quantity of fuel but without higher specific fuel consumption (SFC), thanks to higher efficiencies of fuel pump and combustion chamber, by new regulation of nozzles and by improved fuel dispersion [5]. See Fig. 3, left side.

2.2.3 Temperature and compression of air versus geometry of compressor

Increase of flue gas temperature (17) by higher air compression (11) in larger compressor could lead to undesirable increase in engine diameter and engine frontal area (5). Possible formulation of contradiction:

TC14: temperature 17/5 area: HP: **3**,**35**,39,18 and TC15: pressure11/5 area: HP:**10**,**15**,36, 28.

Heuristic principles: Local quality (HP3), Change of physical-chemical parameters (HP35), Preliminary action (HP10) and Dynamics (15) could be inspirational and were applied.

Higher temperature of flue gas was achieved by higher air compression but without extension of compressor and frontal area, thanks to higher compressor speed and optimization of most components: both diameters and blades geometry of compressor, radial and axial diffusers, combustion chamber, and guide-wheel and action-wheel of the turbine. See Fig. 3, left side.

2.2.4 Expensive and cheap, resistant and low-resistant material

Causes of the mentioned TC7-12 could be formulated inside, it means numerous causal physical contradictions (FCs) with contradictory demands on the individual parts could be formulated on quantity of fuel, on flue gas temperature, on size of frontal area (diameter) of the compressor, possibly also on the material quantity or quality. Then so called separations could be used to solution of FCs. The key FC could be formulated inside of TC7-12.

FC: exposed parts, guide and action wheels of the turbine, must have a high melting point for prolongation of working life (reliability) of exposed parts, but they must have also a low melting point for maintaining the cheapness of originally used material (Inconel).

Physical contradiction was solved by separation in space and by structural change of the surface; both in accordance with standard solution models, as it is known from Sub-Field analysis (see 2.2.5)and thanks to new technology of coating (2.2.6).

2.2.5 Standard solution – three times

In the innovated engine TJ100S-125 by utility model No. 25292 "Design of flow parts of turbojet engines" [4] – the standard way of softening of harmful interaction between two substances was applied, as it is known from Sub-Field analysis.

Specifically, the harmful heat effects of exhaust gas (S1) on the exposed components (guide-wheel and action-wheel, S2) were limited by introduction of external supplement (protective coating) on the components surface, namely two times. Standard paterns are shown in Fig. 4.

At first a casting made of nickel-based super alloy Inconel 713 LC (S2) was coated by "external supplement" – aluminium layer (*Al*) by new developed technology „Chemical Vapour Deposition - Out of pack" [4]. Fig. 4a.

Then the unsufficient diffusion of *Al* inside alloy Inconel 713 LC was reinforced by heat action. These coating *Al* (Fig. 4a) and diffusion *Al* (Fig 4b) improved the thermal oxidation resistance of cheap super alloy Inconel (S2) against harm action of hot gases (S1). Fig. 4a, b.

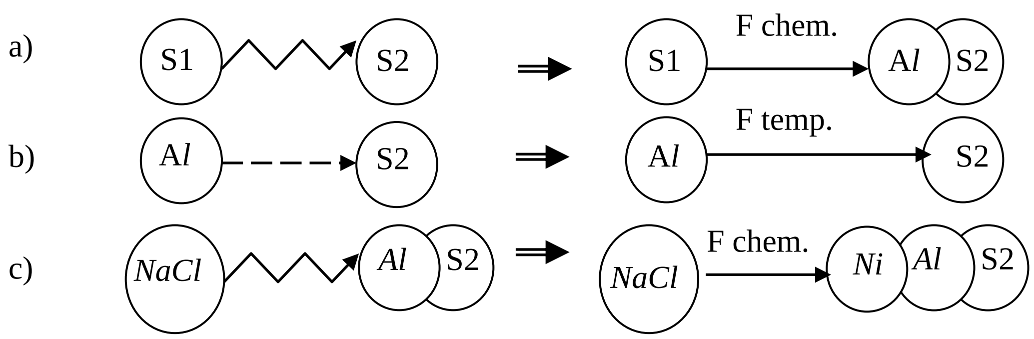


Fig. 4. Weakening of harmful action (a, c) and improving an insufficient diffusion (b).

Now there is prepared further improvement of resistance of external *Al* supplement, by external supplement again, namely by *Ni* coating for increase the corrosion resistance, especially against *NaCl* (Fig. 4c). It is motivated by requirements of naval forces to apply TJ100S-125 engines for air targets starting from the aircraf carriers.

2.2.6 Merging of two alternative methods of coating

Protective *Al* coating was deposited by new developed technology of coating [4]. In terms of TRIZ the new developed method merges two alternative methods [9].
The existing two alternative coating methods, „CVD-Chemical Vapour Deposition" and coating in „Pack cementation", were merged into a new coating method „CDV-Out of Pack", which combines advantages and suppresses disadvantages of both alternative methods [9], as shown in Table 4.

Table 4. Merging of two alternative methods of coating in one new method

Method of coating	Contactless gas deposition (CVD)	Contact gas deposition (Pack cementation)	New Contactless gas deposition (CDV - Out of Pack)
Components in contact with the powder	+ (separation)	- (contact)	+ (separation)
External generator of deposit gas	- (existence)	+ (absence)	+ (absence)
Adhering of the powder on the components	+ (non-adhering)	- (adhering)	+ (non-adhering)
Release of gases inside the retort	- (outside)	+ (inside)	+ (inside)

In addition, the new method provides advantageous possibilities, additional advantages:

- Application of a powder with the grain size greater than in “Pack cementation”, which reduces the proportion of dust adhering to the coated components;
- A small amount of powder consumed;
- A small amount of generated gases to be subsequently neutralized;
- Possibility to coat parts in the inert gas Ar.

Protective *Al* coatings against oxidation and then *Ni* coatings against corrosion, both deposited by the new method, allowed to increase the thrust (temperature of gases) and also significantly extend the working life (reliability) of the engine. Those are contradictory goals usually solved only through compromise, optimization. In the new engine TJ100S-125 the contradiction was overcome, the thrust was improved; working life and reliability were significantly increased. Visible map of corresponding TC7-TC12: see Fig. 3, left upper side.

2.2.7 Dynamism

The engine controllability was improved thanks to the fact that the amount of injected fuel depends now almost linearly only on the pump speed [5]. The pump efficiency was increased by 15%. The fuel pressure and number of injection nozzles increased, the quality of injected fuel spray was improved. The engine restart ability was improved up to 6 000 m.

New solution of TJ100S-125 engine can be evaluated in terms of TRIZ as follows:

- Successful overcoming of numerous contradictions (Fig. 3, left side),
- Standard solutions of three substance conflicts (Fig. 4 a, b, c),
- Merging of two alternative methods to a new coating method CDV-Out of Pack (Table 4),
- Increasing of controllability of fuel injection and the dynamism of the whole engine [5].

3. Conclusion

The innovation of small turbojet engine was evaluated using TRIZ tools two times. First, the innovation of turbojet engine was evaluated by 16 experts from universities and research institutions – the members of evaluation committee - on the base of five criteria (novelty, invention, rank of innovation, difference of the main and additional functions) in the competition for the Gold Medal at the International Engineering Fair in Brno, 2013.

Then the secretary of the evaluation committee and the second author of this article looked for deeper causes, which led the inventor to successful innovation. Several causes, that is overcoming numerous contradictions, standard solution patterns, merged alternative devices and methods were identified in the innovation and described in this article.

The question arises how much and whether TRIZ methodology was or was not used, namely during improvements of the small turbojet engine. The contradictory answer can be formulated as: “yes and no”; i.e. objectively and intuitively and partly yes, subjectively and consciously and completely not. The main designer and the director of the Air Division PSB Velká Bíteš, inventor and first author of this paper used objectively and intuitively several solving tools known from the TRIZ methodology. Subjectively, he did not used TRIZ methodology consciously. While innovating the engine he used lifetime knowledge and experience of designer, regardless of numerous sceptical views of dubious people around.

However, the mentioned contradictory statement “yes and no” is not in contradiction with the fact that the TRIZ methodology can be studied, mastered, practically applied and hence can be consciously used in education as well as in technical creative work. Therefore, it remains a permanent challenge for MATRIZ colleagues to strengthen the subjective creative intuition in education and practice with the objective analytical and synthetic TRIZ methodology.

If colleagues find the successful innovation of small turbojet engine applicable as a “case study” in education of students and engineers in companies, the article fulfilled its purpose.

Acknowledgements

Author(s) gratefully acknowledge(s) financial support from the Ministry of Education, Youth and Sports under projects No. LO1210 – „Energy for Sustainable Development (EN-PUR)“ .

References

1. Bušov B., Jirman P. „How to improve the evaluation of exhibits by partial application of TRIZ“, TRIZ Future, Dublin, Ireland, 2011

2. Utility design No. 12724, „ Jet Motor or turbine motor”, 23. 10. 2002

3. Patent China, No. ZL03821260.9, „Jet Motor or turbine motor“, 31. 12. 2008

4. Utility design No. 25292 „Design of flow parts of jet and turbine engines“, 29. 4. 2013

5. Patent CZ 304 401 „Regulátoru palivových trysek s obtokem“, 5. 3. 2014

6. Katolický Z. “Documents of turbine engine TJ100 and TJ100S-125”, PBS Velká Bíteš, 2013

7. Souchkov V. “Differentiating Among the Five Levels of Solutions”, TRIZ-Journal, July, 2007

8. Souchkov V. ”TRIZ and systematic innovation”, 5-Day Advanced Course, Utrecht, The Netherlands, November , 2009

9. Devoyno I. G.: “Improving of technical systems by TRIZ approaches”, Minsk, (orig. in Russian translated into Czech, Brno, 1996)

Author (co-author) to contact: Bohuslav Bušov, busov@feec.vutbr.cz

TRIZfest 2014

Standard VDI 4521: Solving Inventive Problems with TRIZ (Status)

Hiltmann, Kai[1], Souchkov, Valeri[2]; Thurnes, Christian[3]; Adunka, Robert[4]; Koltze, Karl[5]; Livotov, Pavel[6], Mayer, Oliver[7]; Müller, Wolfgang[8]

[1]*Coburg University of Applied Science and Arts, 96450 Coburg, Germany*
[2]*ICG Training & Consulting, 7511KH Enschede, the Netherlands*
[3]*Kaiserslautern University of Applied Science, Kaiserslautern, Germany*
[4]*Siemens AG, Germany*
[5]*Niederrhein University of Applied Science, Niederrhein, Germany*
[6]*Offenburg University of Applied Science, Offenburg, Germany*
[7]*GE Global Research, Germany*
[8]*VDI, Germany*

Abstract

The process of establishing an industry standard for TRIZ has been initiated: VDI Guideline 4521 will cover TRIZ. Work is going on on the first part of the standard which will define and explain basic TRIZ vocabulary and notions. A first draft of a list of terms has been compiled by V. Souchkov and is currently being discussed at MATRIZ. The standardization committee consists of TRIZ specialists of various degrees together with TRIZ users from industry. It is working in close connection with MATRIZ. In parallel, translations for the elements of TRIZ terminology into several languages are being sought. According to schedule, work on the first part of the standard may be finished by July 2014 and may go into print by the end of the year.

1. Introduction

It has been only after the falling of the Iron Curtain in the year 1989 that TRIZ got known in Western Europe. In the amount of literature that emerged in the following years, different terms were being used for ideas and methods, different interpretations were given, and new tools were promoted. For the student of TRIZ and the interested new user, the various appearances of the methodology were hardly comparable among each other which lead to confusion and obstructed deeper understanding. Users would therefore incline to seek their own interpretation to the content they thought to have understood and refrain from applying more complex methods.

There are even more drawbacks of this situation:

1. TRIZ is a complex set of methods, some of these based on a complex set of underlying ideas and presumptions, and was brought up in a cultural environment which can not readily be accessed by users who were not socialized in a communist society. This fact inevitably leads to difficulties in understanding the presumptions of TRIZ theory.

2. The complexity of the methodology urges students to rely on multiple sources. A student must therefore be able to compare explanations of a specific concept in several sources of literature.
3. We are living in a fast and rather impatient period of time. Individuals interested in learning and, first of all, employing a promising method do not expect training periods of several years. They will therefore give up their efforts after some time and confine themselves to what they have absorbed to that time.
4. New methods for technical innovation are coming up and will merge with TRIZ techniques, making it harder to sort out differences and unique ideas of either approach.
5. It is difficult for users to exchange ideas and opinions on TRIZ using –often unwittingly – different technical languages.
6. A new concept which is still under dispute does not represent the state of the art. In order to make TRIZ a tool, approved by science and experts, which is worth being part of engineering standard education, a general description of basic TRIZ is required.
7. Finally, science is distinguished by the possibility to falsify theses, or at least to check their plausibilities. This, on the other hand, requires their description and communication in a common language. The common language thus is a means to improve the scientific base of TRIZ theory.

The state of the art in technology uses to be described in a standard. We have therefore taken the initiative to establish an engineering standard on basic TRIZ. Among the organizations suitable for this task, we have chosen VDI, the German Engineer's Association. Advantages of a VDI standard or Guideline comprise comparatively low formal requirements and the practical character of VDI Guidelines. The fact that VDI is a German institution does not mean any hindrance to application in the international community – the standard can be composed in several languages and, if there is need to do so, can later even evolve into an ISO standard.

2. VDI Standards

VDI, the Association of German Engineers, founded in 1856 and representing 150 000 members 0, sees its mission in acting for engineers and engineering in society. This comprises inspiring young people for technical science, consulting engineers and supporting members in difficulties, consulting governmental institutions, and conducting extensive standardization work. There are some 2000 valid VDI Guidelines at this moment 0.

Characteristics of these standards are:

- VDI guidelines are made by engineers for engineers
- VDI guidelines describe the state of the art
- VDI guidelines are generally approved technical rules
- The majority of the guidelines is multilingual

The scope of the guidelines is the subsumption of the state of the art in all areas of technology. Standards are available as single documents or collected in 60 handbooks on specific technical fields. The standardization process and its objectives are defined in standard VDI 1000 part of which is available online 0.

VDI is organized into 55 technical divisions among which the VDI Society Product and Process Design 0 is responsible for the Board of Innovation Methodology. This board has 26 members, including the authors. All the members have experience in TRIZ; they represent in equal shares counseling (8), industry (8), and academia (10). VDI has reached an agreement with DIN, the German national institute for standardization, that the subject of TRIZ will be covered by VDI, so no double effort on this subject will occur. There is, however, work going on with CEN, the European Committee for Standardization. CEN is editing a Technical Specification 0 TS 16555 which will point out various aspects of innovation management but will not prescribe specific methods to be used 0.

According to VDI 1000, the text of a standard is composed by the board, after which it is published as a draft version. Anybody may then raise objections against the standard within a period of six months. Objections will then be examined by the board and, if appropriate, incorporated into the standard. The valid guideline is finally published within 6 months after the objections deadline.

3. Standardizing TRIZ: Yes or no?

The topic of setting up a standard was informally brought up on the TRIZ Future Conference in October 2012, on TRIZfest in Kiev in August 2013, as well as on TRIZ discussion boards on Xing and Linked-In. It was formally announced on TRIZ Future Conference 2013 in Paris where it was clearly welcomed. With the majority, including TRIZ masters, supporting the project, there have nevertheless been some objections:

1. *"Creating a standard might hinder further development of TRIZ"* – standards codify a momentary state of the art but do not hinder further development. A VDI standard will be revised after 5 years and adjusted as far as appropriate. A standard may <u>even facilitate</u> further thinking and developing TRIZ: Complex ideas are difficult to communicate, so a new method can easily refer to a commonly known standard and describe its differences from that.
2. *"Defining "standard" (canonical) and "nonstandard" TRIZ will lead to conflicts between TRIZ schools who are even differing on basic assumptions"* – a VDI standard only attests the state of the art. Methods which are still being developed are not mature for standardization.
3. *"We'd better wait until the standards will form themselves"* – the Iron Curtain has fallen and we are experiencing a fast development of innovation theories. New ideas are evolving, others tend to simplify TRIZ. If no standard is defined, users will randomly get into contact with any fashionable method and pick the first one they reckon to have understood. Obviously, in this way simple theories may take over and the more complex ones may fall into oblivion. This is comparable to Systematic Engineering (VDI 2221) which, though simple enough, must be studied and practised. Since this seems tedious to many an engineer, the method might have been forgotten had it not been standardized – and is now occasionally being reinvented in the framework of quality management. If we do not set a standard after which TRIZ is considered and taught as basic engineering knowledge, TRIZ will therefore be considered a historical but generally forgotten idea 20 years from now. There has also been the concept of construction catalogues (VDI 2222) which enormous amounts of work have been spent on. Until today, those bulky catalogues have hardly ever been employed in design and they would have disappeared in history. Only now with advanced CAD software, this approach is rediscovered (or reinvented) and made available in a comfortable way. This would probably not be the case without the respective VDI standards.
4. *"Review the available literature before doing a lot of work"* – yes, that's what we will do.

5. *"Standards are needed when doing things a "non-standard" way could cause harm"* – standards also make life and work easier, see the metric system or the A4 paper format.
6. Certification: *"organizations that have turned the granting of certificates into money-generating opportunities"* – VDI standards are not intended for money generation. There will not be a commission (besides, maybe, MATRIZ) which certifies that a user does TRIZ the "right" way. A standard will describe elements of TRIZ and any interested party will be able to check if a TRIZ expression or tool is used in the way specified by the standard or not. Besides, doing things differently does not have to bad – it is just different.
7. *"At MATRIZ, we are currently looking at the development of the Glossary of TRIZ terminology with examples. In my opinion, this is a must first step in the development of any TRIZ standard."* – Obviously, there must be close cooperation between the standardization committee and the world TRIZ community in order to avoid double standardization.

4. Work Schedule

In preparation of the project, we talked to members of the TRIZ community to learn about their view of the subject. Several opinions that were given at this time have been cited above. Moreover, the matter was discussed on the internet in the TRIZ board at Linkedin.

Talks with DIN and VDI resulted in the decision for VDI as the project partner. VDI reacted quickly and the first meeting took place on Oct. 10th, 2013, on which Kai Hiltmann was elected chairman of the board.

Meanwhile, V. Souchkov was preparing a collection of TRIZ terms with short explanations on behalf of MATRIZ. The TRIZ board decided to wait for this collection, to base the standard upon it, and to translate the terms into German. The first part of the standard shall contain the basic TRIZ terminology with short explanations. The parts to follow may describe basic conceptions of TRIZ with their specific terminologies.

5. Content of Part 1

Valeri Souchkov's collection of terms was finished as a draft version by February 2014. This version contained a whole of 390 terms, including denominations from the latest developments in TRIZ which cannot yet be called TRIZ standard knowledge, e.g. "stagnation zone" (from flow analysis) or OTSM terminology. On the other hand, the names of the 40 inventive principles and the 76 standard solutions were not included. The board therefore decided to revise the list together with seeking appropriate translations. For that latter purpose, established TRIZ literature was to be examined, and the terminology used there (which users are accustomed to) was to be collected and considered in determining the future standard expression. The literature considered were, first of all, translations of Altshuller's works , but also wide-spread TRIZ literature 0— and also established engineering literature 0. The latter was included because re-definition of established engineering terms should be avoided, if possible.

Too large a committee may not be able to cooperate efficiently enough in this work, so a working group was appointed who would collect established vocabulary and suggest the most basic subset from Souchkov's list, and propose translations. The five members chosen who would make this group were Robert Adunka, Karl Koltze, Pavel Livotov, Oliver Mayer, and Christian Thurnes.

The group presented their work results on May 28th, 2014. To select the basic terms subset from Souchkov's list (which had been augmented by ten terms), each of the group members had rated the importance of a term allotting 0, 3, or 9 points. These were summed up and terms which had received at least 30 points were suggested for the basic list. These terms are listed in **Table 1**. Since this list has been composed just by a numerical method, it has to be checked for thematic consistency. The board members will therefore suggest changes and additions by June 15th, 2014. Also, short explanations of the terms will be made on the basis of Souchkov's list.

VDI guidelines can be multilingual. The board wishes to contribute with its work to the TRIZ community world-wide; on the other hand, the number of languages must be restricted. VDI 4521 is therefore scheduled to be published in English, German, and Russian. Certainly, it would be desirable to standardize terminology and interpretations in more languages. A way to do this would be to translate the contents of the standard and to keep this information at a common location, preferably on the internet. This would then not be part of the standard itself, but a translation referring to the standard.

Table 1: Basic Terms with a rating of at least 30 points (draft version)

English Term	**Proposed Translation**	**English Term**	**Proposed Translation**
40 Inventive Principles	40 Innovationsprinzipien	Key Problem	Kernproblem
76 Standard Solutions	76 Standardlösungen	Key Problem Analysis	Analyse der Schlüsselprobleme
Administrative Contradiction	Administrativer Widerspruch	Laws of Engineering Systems Evolution	Entwicklungsgesetze technischer Systeme
Algorithm of Inventive Problem Solving	Algorithmus zur Lösung von Erfindungsaufgaben - ARIZ	Level of Invention	Erfindungsniveau
Altshuller Matrix	Widerspruchstabelle	Main Useful Function	Primäre nützliche Funktion
Anticipatory Failure Determination	Antizipierende Fehlererkennung (AFE)	MATChEM	MATChEM
Auxiliary Function	Hilfsfunktion	Methods for Eliminating Psychological inertia	Methode zur Überwindung geistiger Trägheit, Kreativitätsmethoden
Basic Function	Hauptfunktion	Modeling with "Smart Little People"	Zwerge-Modell
Bi-System	Bi-System	Multi-Screen Analysis	Neun Felder Denken
Catalogue of Effects	Effektedatenbank	Patent Circumvention	Patentumgehung

Cause-Effect Chains Analysis	Ursache-Wirkungs-Analyse	Physical Contradiction	Physikalischer Widerspruch
Classical TRIZ	Klassisches TRIZ	Physical Effect	Physikalischer Effekt
Component	Komponente	Principle of Separating Contradictory Demands	Separationsprinzipien
Component Model	Komponentenmodel l	Problem Analysis	Problemanalyse
Contradiction	Widerspruch	Psychological Inertia	Psychologische Trägheit
Contradiction Matrix	Widerspruchstabelle	Resource	Ressource
Disadvantage	Nachteil	Resource Analysis	Ressourcenanalyse
Engineering Contradiction	Technischer Widerspruch	S-Curve Analysis	S-Kurven-Analyse
Engineering Parameter	Technischer Parameter	S-Curve of Evolution	S-Kurve der technischen Evolution
Engineering System	Technisches System	Separation of Contradicting Demands	Separationsprinzipien
Evolution Pattern	Evolutionsmuster	Size-Time-Cost Operator	Operator MZK (Maße, Zeit, Kosten)
Feature Transfer	Feature Transfer	Standard Inventive Problem	Standardproblem
Field	Feld	Standard Solution for Solving Inventive Problems	Standardlösung
Function Analysis	Funktionsanalyse	Substance	Stoff
Function Model	Funktionsmodell	Substance-Field Analysis	Stoff-Feld-Analyse
Function-Oriented Search	Funktionsorientierte Suche	Subsystem	Subsystem
Harmful Function	schädliche Funktion	Su-Field	Stoff-Feld-Modell
Ideal Engineering System	Ideales Technisches System	Supersystem	Obersystem
Ideal Final Result	Ideales Endresultat (IER)	System of Inventive Standards	System der Standardlösungen
Ideal Machine	Ideale Maschine	Technical Contradiction	Technischer Widerspruch
Ideality	Idealität	Technical	Technischer Parameter

		Parameter	
Inventive Principle	Innovationsprinzip	Technical System	Technisches System
Inventive Problem	Erfinderisches Problem	Technology Evolution	Technische Evolution
Inventive Problem Solving	Erfinderische Problemlösung	Theory of Inventive Problem Solving	Theorie des erfinderischen Problemlösens
Inventive Standard	Standardlösung	Trimming	Trimmen
Key Disadvantage	Schlüsselnachteile	Useful Function	Nützliche Funktion

Additional content which shall be included in part 1 is an outline of how exemplary problems can be approached using TRIZ and a short history of the method.

6. Further Schedule

The manuscript is scheduled for the end of July, 2014. Usually, the VDI editorial committee will then format the text in the standard layout which may take about 6 months, and then print the text as a draft standard. The public will then be asked for comments within half a year. After this period, the standard will be published and valid. After five years, VDI guidelines use to be revised. The standardization board will then collect comments from the user community and decide if and what changes should be made to the revised edition.

The board has not yet decided on the exact further procedure. The most obvious way to continue work will be further parts of the standard which describe particular procedures of TRIZ. Since VDI standards always are descriptions of the state of the art, procedures must then be selected which meet this criterion.

Board members who take part in TRIZfest 2014 will be glad to discuss this matter on the conference.

References

1. http://en.wikipedia.org/wiki/Verein_Deutscher_Ingenieure, accessed 2014-06-07

2. VDI: VDI-Richtlinien. Duesseldorf, Germany: VDI, 2011.

3. Standard VDI 1000 : 2010-06: VDI Guideline Work: Principles and procedures. http://www.vdi.eu/uploads/tx_vdirili/pdf/1669967.pdf, acc. 2014-06-07

4. http://www.vdi.eu/engineering/technical-divisions/product-and-process-design/, acc. 2014-06-07

5. Technical Specifications, http://www.cen.eu/work/products/TS/Pages/default.aspx , acc. 2014-06-07

6. http://standards.cen.eu/ → "Search Standards" → "innovation" , acc. 2014-06-07

7. Altshuller, G. S.: Creativity as an exact science. New York : Gordon and Breach Science Publishers, 1988: Studies in cybernetics . – ISBN 9780677212305.

8. Altshuller, G. S.: Erfinden – Wege zur Lösung technischer Probleme. Original Title: Творчество как точная наука, Berlin : VEB Verlag Technik, 1986.

9. Koltze, K. und Souchkov, V.: Systematische Innovation. München : Hanser, 2011. – ISBN 978-3-446-42132-5.

10. Herb, R.; Herb, T. und Kohnhauser, V.: TRIZ : Der systematische Weg zur Innovation, Landsberg/Lech : mi Verl. Moderne Industrie, 2000 . – ISBN 3-478-91980-0.

11. Herb, R.; Terninko, J.; Zusman, A. und Zlotin, B.: TRIZ - der Weg zum konkurrenzlosen Erfolgsprodukt. Original Title: Systematic innovation. Landsberg/Lech : Verl. Moderne Industrie, 1998. – ISBN 3-478-91920-7.

12. Hentschel, C.; Gundlach, C. and Nähler, H. T.: TRIZ. München : Hanser, 2010. – ISBN 978-3-446-42333-6.

13. Livotov, P.; Petrov, V.: Innovationstechnologie TRIZ. Produktentwicklung und Problemlösung.

14. Gimpel, B.; Herb, T. und Herb, R.: Ideen finden, Produkte entwickeln mit TRIZ. München : Hanser, 2000 . – ISBN 3-446-21159-4.

15. Qualitätsmanagement in der Automobilindustrie. VDA Volume 6: Part 1. Berlin: Beuth, 2010.

Author (co-author) to contact: Kai Hiltmann, kai.hiltmann@hs-coburg.de

TRIZfest 2014

Systematic Approach to Problem Solving of Low Quality Arc Welding during Pipeline Maintenance Using ARIZ

TriZit Benjaboonyazit

Faculty of Engineering, Thai-Nichi Institute of Technology
1771/1 Pattanakarn Rd., Suanluang, Bangkok 10250, Thailand

Abstract

In this paper, the problem of low quality arc welding during pipeline maintenance due to residual magnetic field on the pipeline caused by MFL inspection device is systematically analyzed to find the root causes of the problem, and ideal solution of which internal resources are utilized, is attained by using ARIZ. Computer simulation using finite element method and field test are conducted and show satisfactory result for the proposed idea.

Keywords: TRIZ, ARIZ, MFL, innovation tools, residual magnetic field, arc welding

1. Introduction

Magnetic flux leakage (MFL) technique is a nondestructive testing method that is widely used to detect corrosion and metal loss in steel pipelines. During pipeline maintenance, the MFL device, typically known as a "PIG" travels inside a pipeline to inspect the corrosion parts with a powerful magnet which is used to magnetize the pipelines. The wall of the pipeline is magnetized axially to near saturation flux density. If, at some point, the wall thickness is reduced by a defect or corrosion, a higher fraction of magnetic flux will leak from the wall. The magnetic flux leakage will be detected by magnetic sensors placed between the poles of the powerful magnet and data are sent to the outside recording device for analysis. Problem occurs when it is necessary to remove the damaged segment of the pipe and replace it with the new ones by welding them to the existing pipelines. It is found that welding rod and arc column are subjected to some kind of force that causes them to deviate from the right position and sometime the arc is even blown away. This phenomenon is known as the magnetic arc blow problem where the cause of it is explained as the interaction between the magnetic field of the welding arc and the field of the residual magnetism which may result in poor quality welding. Many methods have been suggested to overcome arc blow problem such as using C-shape permanent magnet placed across the weld joint to compensate for the residual magnetic field [1], or using ground lead of DCEN welding machine wrapped over the pipe to generate compensating magnetic field [2]. But there is no clear explanation on how these methods were derived and whether there are any other ideal solutions for the problem.

As ARIZ is known as a powerful innovation tool, in this paper, the author attempts to find the root causes of the problem and solve the key problem to search for ideal solution of which internal resources are utilized by using ARIZ. Finally, computer simulation using finite element method and field test are conducted to evaluate the proposed idea.

1. Methodology

The methodology used in this paper is comprised of FA (Function Analysis) CECA (Cause-Effect Chains Analysis) and ARIZ (Algorithm of Inventive Problem Solving). FA and CECA are used to analyze the problem to find key problem after which ARIZ is deployed to solve it and search for ideal solutions as in Fig. 1.

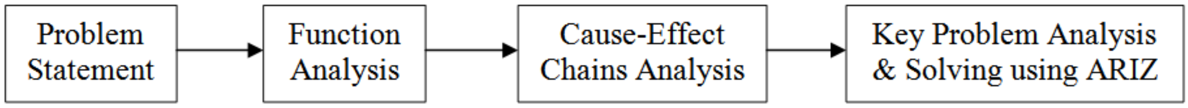


Fig. 1. Roadmap of the problem solving process

3. Problem Statement

3.1. Initial Problem Situation

An MFL device with strong permanent magnet is used to magnetize the pipe wall to nearly saturation level while traveling through the pipelines. Magnetic field leakage at the corrosion part will be detected by magnetic sensors on the MFL device. After corrosion part of the pipeline is located, the damaged segment is cut off and replaced with new ones by welding them to the existing pipeline, the welding engineer at the worksite experiences difficulty in maintaining the position of arc column which is subjected to some kind of force that causes it to deviate from the right position, thus render the low quality of arc welding.

The pipeline is made of carbon steel API5L-X42 with outside diameter as 6 inch and wall thickness as 6.35 mm. The welding process is Shielded Metal Arc Welding (SMAW) on DC type arc welding machine with Electrode Positive (DCEP). The welding rod is of 3.2 mm in diameter and the welding current is in the range of 90-130 A. The weld joint is prepared by furnishing the pipe with squared ends and beveled edges so that, when placed with ends about 1/16-inch apart, there is a V-groove all the way around the joint where the welding metal is applied. The groove angle is about 75 degrees for pipe with a wall thickness of 1/4 inch or less as stated in the Standards for pipeline welds [3].

3.2. Function Analysis and Cause-Effect Chains Analysis

The process of SMAW arc welding can be described as follows, electric power source supplies current to the welding rod through electrode lead and welding clip, the current flows through the arc column to the pipe and returns to power source through grounding clamp and grounding wire. The arc column is started by tapping or scratching the welding rod against the pipe to create_short circuit where large current flow causes high temperature at contact point. When welding rod departs from pipeline, the heat and electric field at the contact point will causes air between welding rod and pipe to ionize and become conductive. The current will flow through the conductive plasma, causing it to become an arc column. The heat from the arc column will melt the welding rod to create weld bead which will join the heated pipelines together.

Components in the pipeline welding system are listed as in Table 1.

Table 1. Components in the pipeline welding system

Engineering System	Pipeline welding system
Components	Pipeline, Welding rod, Arc column, Power source, Electrode lead, Grounding wire, Grounding clamp, Welder's hand, Air, Electric current, Electric field, Magnetic field, Heat (Thermal field), Weld bead, Residual magnetic field
Super system Components	MFL Device

Function Model is created to analyze the interaction or function among each component in the pipeline welding system. It is found that the current flow in the welding rod and arc column will create magnetic field around them which will interact with the residual magnetic field in the pipeline caused by MFL device or "PIG" under the non-destructive inspection process as shown in Fig. 2.

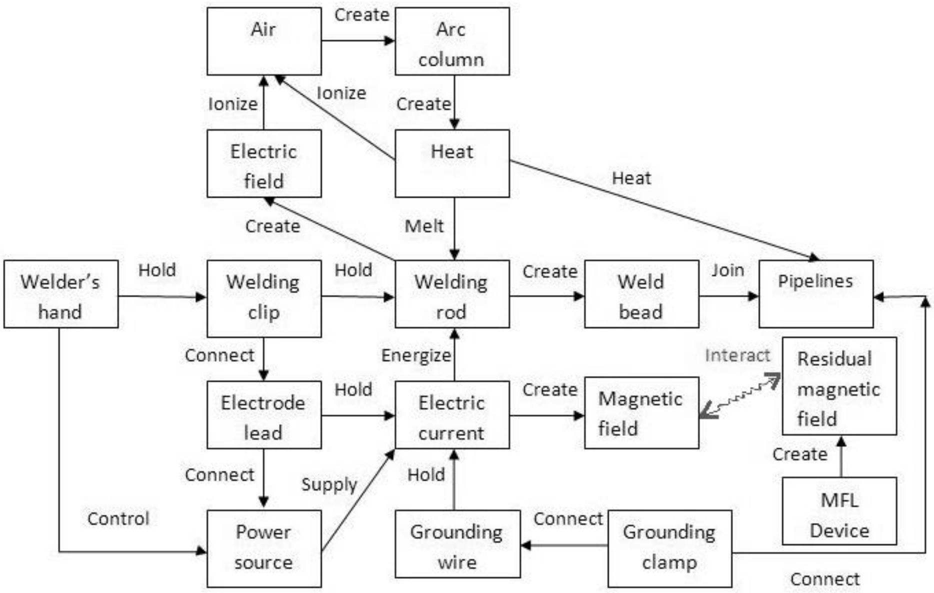


Fig. 2. Function Model of the pipeline welding system

Cause-Effect Chains Diagram is created to analyze the root cause of the problem. The problem or Target Disadvantage is the low quality of welding. Cause-Effect Chains Analysis is applied to identify Key Disadvantages or root causes and the Key Disadvantages are identified as MFL running through the pipeline and Current flow in arc column as shown in Fig. 3. which suggests us to change to different non destructive inspection system or welding system. But since it is difficult to change the method of MFL non-destructive inspection system and the electric arc welding system, the Key Disadvantages is considered as residual magnetic field in pipeline and magnetic field around arc column which combine to create unbalance of magnetic flux around the arc column which is the key problem that make arc column deviated from the right position and renders low quality of welding.

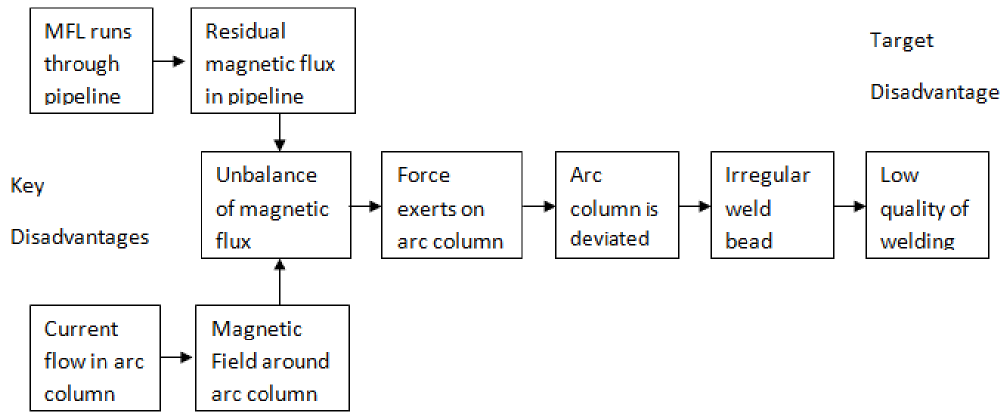


Fig. 3. Cause-Effect Chains Diagram of the problem of low quality of welding

4. Problem Solving with ARIZ

4.1. Part 1. Analyzing the Problem

Step 1.1 Formulate the Mini-Problem

The pipeline welding system has the main function of joining the pipelines after replacing the corrosion segment with the new one. The system consists of main components as Residual magnetic field, Arc welding machine, Pipeline, Welding rod and Arc column.

Mini-problem is formulated as follows.

It is necessary, with minimum changes to the system, to maintain the residual magnetic field for detecting corrosion part during non-destructive inspection process without deviating the arc column during the arc welding process.

Step 1.2 Define the Conflicting Elements

The Conflicting Elements includes Product and Tool which, are defined as follows,
Products: Detecting corrosion part and Deviating arc column
Tool: Residual magnetic field
Step 1.3 Build Graphical Models for the Technical Contradictions
Technical Contradictions (TC) are formulated as follows,
TC-1: If the Residual magnetic field is strong, it is easy to detect corrosion part, but the arc column will be deviated.
TC-2: If the Residual magnetic field is weak, the arc column can be positioned correctly, but it is difficult to detect corrosion part.

The Graphical Models for TC-1and TC-2 are built as shown in Fig. 4(a) and Fig. 4(b) Respectively

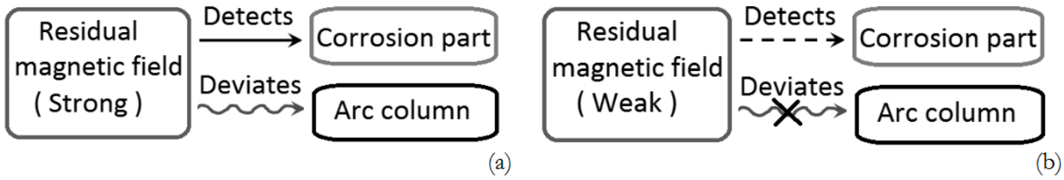


Fig. 4. Graphical Models for the Technical Contradictions

Step 1.4 Select a Graphical Model for Further Analysis

Since the main function of the pipeline welding system is joining the pipelines with good quality of welding, the arc column must not be deviated by Residual magnetic field. Thus, we should choose TC-2 which states that with weak Residual magnetic field, the arc column can be positioned correctly, but it is difficult to detect corrosion part. This is impossible without changing the mechanism of MFL device which goes beyond the mini problem defined in step 1.1. Thus, we try to look at the problem from another direction. TC-1 is selected as Graphical Model for further analysis. In this case, with strong Residual magnetic field, it is easy to detect corrosion part, but the arc column will be deviated. So we try to solve the problem of eliminating harmful effect of Residual magnetic field in the following steps.

Step 1.5 Intensify the Conflict
In order not to compromise (trade off) useful function with harmful effect, we intensify the conflict by considering that instead of “Strong Residual magnetic field”, it is replaced by a “Very strong Residual magnetic field” in TC-1 as shown in Fig. 5(a).

Step 1.6 Formulate the Problem Model
Find an element “X“ that maintains the feature of the very strong residual magnetic field for detecting corrosion part during non-destructive inspection process while also protecting the arc column from being deviated during the arc welding process as shown in Fig. 5(b).

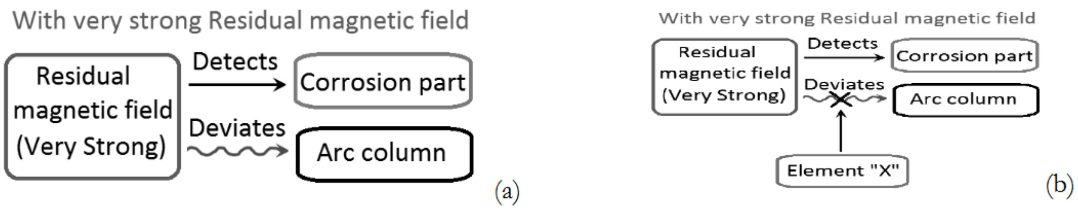


Fig. 5. Intensified conflict model (a) and New problem model (b)

Step 1.7 Apply the System of Standard Solutions
In this step the graphical model is analyzed using substance-field modeling and analysis [4] along with system of standard solutions [5] to find element “X“ as follows,

The initial model is created with S1(object) as Pipeline, S2(tool) as Arc column, F1 as Residual magnetic field and F2 as Welding current. While welding Pipeline with Welding current (F2) through Arc column, Residual magnetic field (F1) causes a harmful function by exerting force through the pipeline to deviate the arc column. The useful function (weld) becomes insufficient (Dashed line) as shown in Fig. 6(a).

In order to eliminate the harmful effect in the system, the standard solution which corresponds to the above initial model is standard solution 1.2.5 which states as follows,
Standard solution 1.2.5 “Switching Off” a Magnetic Influence as shown in Fig. 6(b).

If it is necessary to eliminate the harmful effect of a magnetic field in a Substance-Field Model, the problem can be solved by applying the physical effects which are capable of “switching off” the ferromagnetic properties of substances, for example, by demagnetizing during an impact or during heating above the Curie point.

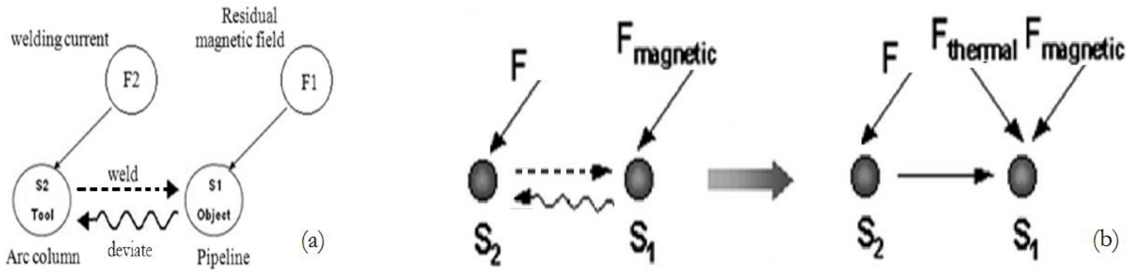


Fig. 6. The initial model (a) and Standard solution 1.2.5 (b)

Standard solution 1.2.5 gives us a hint to find some other fields to destroy the residual magnetic field in the pipeline. Several ideas are generated as follows,
Idea 1: Use thermal field: Heat the pipe above its Curie point so that it might lose its ferromagnetic properties.

Idea 2: Use mechanical field: Hit the pipe with a hammer. This might destroy the alignment of the residual magnetic field in the pipeline.

Idea 3: Use magnetic field: Use permanent magnet to rub the pipeline. This might demagnetize the residual magnetic field in the pipeline.

Idea 4: Use electric field: Use an alternate current solenoid to alter the magnetic dipole's order. This might destroy the alignment of the residual magnetic field in the pipeline.

Evaluation

After doing some field-test. It is found that all the methods in the above ideas are not practical to be implemented. Although they can be applied to a small piece of permanent magnet, but the structure of the magnetized steel pipeline is too large to use the methods of heating, hammering, rubbing or using alternate current solenoid to remove the residual magnetic field in the pipeline.

4.2. Part 2. Analyzing the Problem Model

If the problem is easily solved within Part 1, there is no need to go further into Part 2.

Part 2 and other Parts that follow will deal with solving complex problem as in the following steps.

Step 2.1 Define the Operational Zone (OZ)
In the problem of pipeline welding system, the Operational Zone is defined to be the place around the welding zone between welding rod and pipeline.

Step 2.2 Define the Operational Time (OT)
In the problem of pipeline welding system, the Operational Time is defined to be the sum of the period of time before the welding (T1) and the period of time during the welding (T2) where conflict occurs during the welding time as shown in Fig. 7.

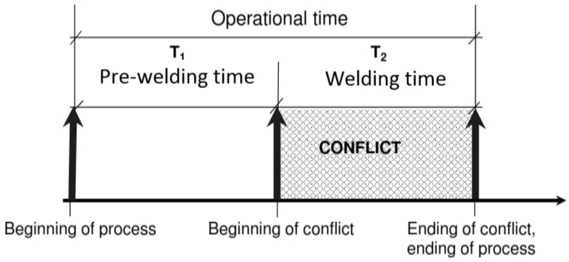


Fig. 7. Operational Time

Step 2.3 Define the Substance Field Resources

The main idea of using substance-field resources is to use any changes in parameters of existing system substance and field resources (including the natural environment) for system problem solving and development [6]. At this state, we create a list of Substance-Field Resources with their parameters as in Table 2.

Table 2. Substance-Field Resources

Substance-Field Resources	Type	Parameters
Heat from the welding current	Field	Temperature
Magnetic field from welding current	Field	Intensity, Direction
Welding current	Field	Amplitude, Frequency
Electrode lead	Substance	Length, diameter, conductivity
Pipeline	Substance	Length, diameter, conductivity
Earth Magnetic line	Field	Intensity, Direction
Gravity	Field	Weight

4.3. Part 3. Formulating the Ideal Final Result and Physical Contradiction

Step 3.1 Identify the Formula for IFR-1

Ideal Final Result (IFR) is used to define the problem to be solved [7]. The Ideal Final Result by introducing the X element is defined as follows,

While neither complicating the system nor causing harmful effects, element "X" eliminates the harmful effect of the very strong residual magnetic field to deviate the arc column during operational time within the conflict zone while preserving the ability of the very strong residual magnetic field to detect corrosion part of the pipeline during non-destructive inspection process as shown in Fig. 8(a).

Step 3.2 Intensify the Formula for IFR-1

We intensify the formula of IFR-1 by introducing an additional requirement that the X element comes from substance field resources. In this case, "Magnetic field from welding current" is considered first with its parameter intensity and direction to replace the X element.

IFR-1: While neither complicating the system nor causing harmful effects, "Magnetic field from welding current" with proper intensity and direction eliminates the harmful effect of the very strong residual magnetic field to deviate the arc column during operational time within the conflict zone while preserving the ability of the very strong residual magnetic field to detect corrosion part of the pipeline during non-destructive inspection process as shown in Fig. 8(b).

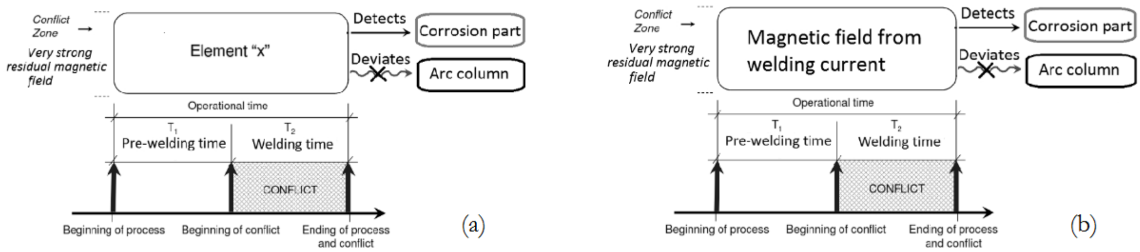


Fig. 8. Ideal Final Result (IFR-1) (a) and Intensified IFR-1 (b)

Step 3.3 Formulate the Physical Contradiction for the Macro-Level

The Physical Contradiction (PC) [8] for the Macro-Level is formulated as follows,
"Magnetic field from welding current" should have proper intensity and direction during welding time to eliminate the harmful effect of the very strong residual magnetic field, and should have no intensity and direction during pre-welding time to preserve the ability of the very strong residual magnetic field to detect corrosion part as shown in Fig. 9(a).

Step 3.4 Formulate the Physical Contradiction for the Micro-Level
The Physical Contradiction for the Micro-Level is formulated as follows,

"Free electrons" should flow around the pipe in the conflict zone to create proper intensity and direction of magnetic field during welding time to eliminate the harmful effect of the very strong residual magnetic field, and should not flow around the pipe in the conflict zone during pre-welding time to preserve the ability of the very strong residual magnetic field to detect corrosion part as shown in Fig. 9(b).

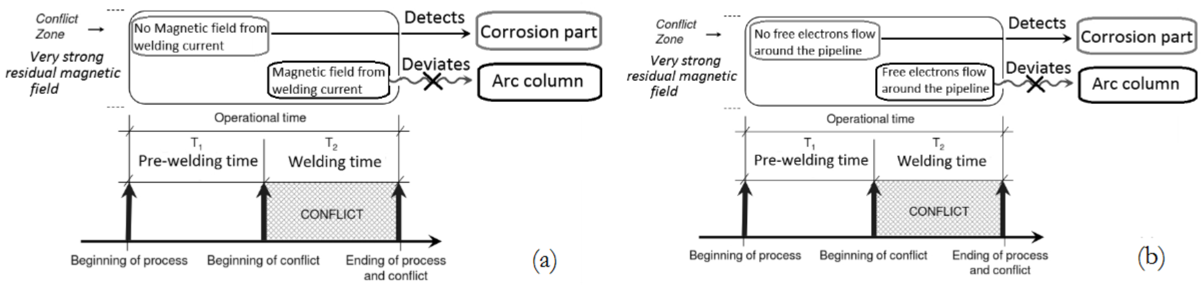


Fig. 9. Physical Contradiction for the Macro-Level (a) and Micro-Level (b)

Step 3.5 Formulate the Ideal Final Result (IFR-2)

The Ideal Final Result (IFR-2) from the Physical Contradiction for the Micro-Level is formulated as follows,
IFR-2: "Free electrons" should, on their own, flow around the pipe in the conflict zone to create proper intensity and direction of magnetic field during welding time to eliminate the harmful effect of the very strong residual magnetic field, and should be, on their own, neutralized during pre-welding time to preserve the ability of the very strong residual magnetic field to detect corrosion part.
Step 3.6 Consider Solving the New Problem using the System of Standard Solutions

Consider Solving the New Problem in step 3.5 using Standard solution 1.2.5 once again as in Step 1.7 with magnetic field from welding current as resource to generate ideas.

Idea 5: Use “Magnetic field from welding current”

Magnetic field from welding current is a derived resource in the system and can be utilized to counteract the residual magnetic field in the pipeline locally at the welding zone during the welding time. By winding the electrode lead and grounding wire around the pipe near the welding zone with proper amount of turns and direction, the free electrons will, on their own, flow around the pipe in the conflict zone to create proper intensity and direction of magnetic field during welding time as soon as the arc column is initiated, and during the non-destructive inspection process before the welding time, no free electron is flowing around the pipe, thus, the ability of the residual magnetic field to detect corrosion part can be preserved.

Although we use the same Standard solution 1.2.5 as in Step 1.7, the difference is that with all the substance field resources at hand, we can have a deeper insight into how the problem could be solved ideally. Besides, TRIZ’s Inventive Principle [9] Number 3 ‘Local Quality’ helps us to overcome our psychological inertia by giving a hint that instead of demagnetizing the entire pipeline, we can just demagnetize only the welding zone locally.

We also look for other ideas by going back to step 3.2 and replace X element with other substance field resources such as heat from welding current and repeat the process of part 3 again to get the idea of heating the welding zone locally which might neutralize its ferromagnetic properties (**Idea 6**), and we also go further into other parts of ARIZ to mobilize resources and apply TRIZ’s knowledge base to come up with an idea of using the AC mode of the existing welding machine to create strong alternate magnetic field at the welding zone to destroy the alignment of the residual magnetic field in the pipeline locally (**Idea 7**).
In this case, idea 5 of using “Magnetic field from welding current” to counteract the residual magnetic field in the pipeline is considered to be more suitable and is adopted as potential solution to be evaluated with computer simulation and field test.

5. Potential Solution

The electrode lead and grounding wire can be wound around the pipe to generate constant magnetic field across the welding zone. With proper intensity and direction of the magnetic field, the residual magnetic field across the welding zone can be reduced to the value that it will no longer cause harmful effect to deviate the arc column which renders low quality of welding as shown in Fig. 10.

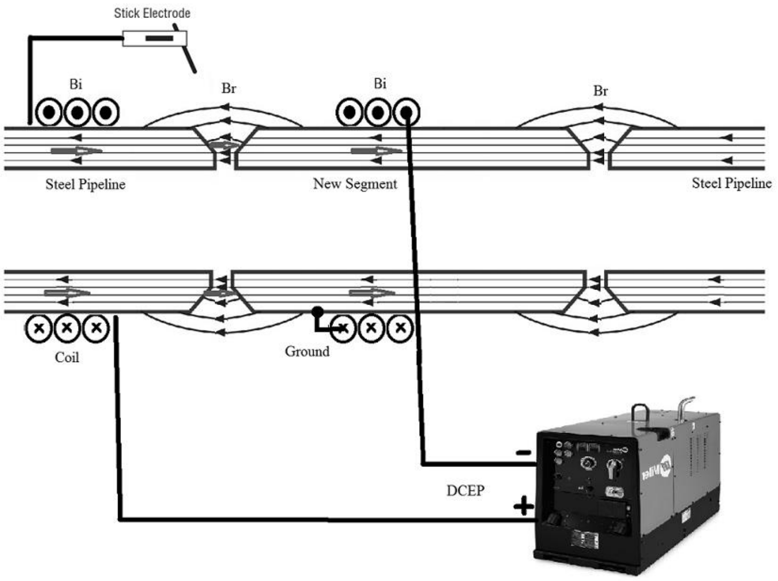


Fig. 10. Potential Solution

6. Magnetic Field Simulation and Field Test

For magnetic field simulation, the software of Finite Element Method Magnetics (FEMM]) is used to develop an axisymmetric model of the pipeline with V-groove and coils on it. The pipeline model is divided into 3 parts with new segment that has no residual magnetic field in the middle. The other 2 parts of steel pipeline at both ends has residual magnetic field and acts like permanent magnets. The magnetic property of the steel pipeline is assumed to have the same property as the test result from Southwest Research Institute [10]

The result of magnetic field simulation with no compensation coils shows a large amount of magnetic flux leaking at the V-groove as shown in Fig. 11(a). With proper compensation coils, magnetic field simulation shows reduction in amount of magnetic flux leaking at the V-groove as shown in Fig. 11(b).

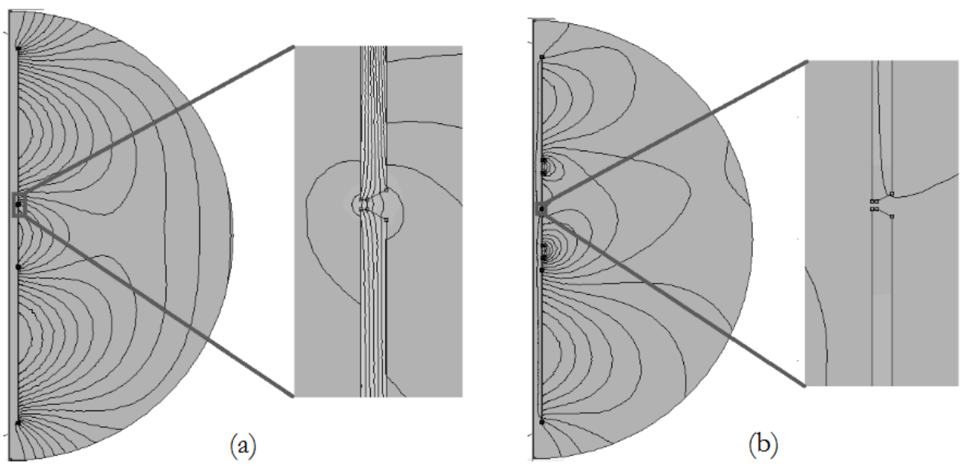


Fig. 11. Magnetic field with no compensation (a) and with compensation (b)

Magnetic fields at the V-groove are calculated at different location in the V-groove as Bvs at the pipe surface level of the V-groove, Bvm at the middle of the V-groove, and Bvr at the middle of the root pass in the V-groove, with the welding current and the number of turns as parameters. The results are displayed as table and graphs in Fig. 12.

I (Amp)	N (Turn)	IN (Amp-Turn)	Bvs (Gauss)	Bvm (Gauss)	Bvr (Gauss)
90	12	1080	75	158	224
100	12	1200	54	119	169
110	12	1320	34	79	114
120	12	1440	12	38	58
125	12	1500	2	17	29
130	12	1560	-9	-4	0.3
90	15	1350	28	68	100
100	15	1500	2	17	29
110	15	1650	-26	-37	-45
120	15	1800	-56	-94	-124
125	15	1875	-72	-125	-166
130	15	1950	-89	-157	-210

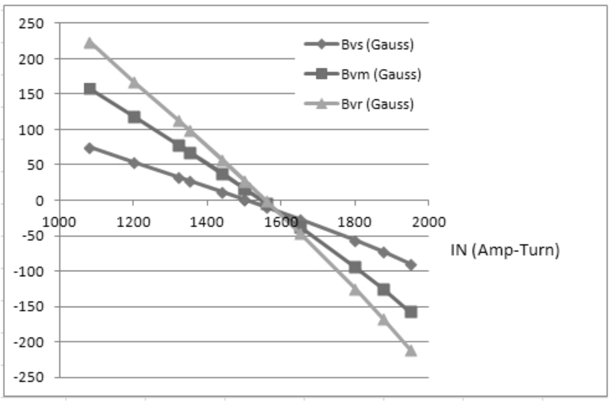


Fig. 12. The table and graphs of resultant magnetic fields at the V-groove

Fig. 12. shows that the magnetic fields at different location in the V-groove varies linearly with the magnetomotive force. With low magnetomotive force, it is undercompensated while with high magnetomotive force, it is overcompensated. From the graph in Fig. 12, the proper value of magnetomotive force that will keep magnetic fields in the V-groove under 30 Gauss so that it will not cause arc blow is around 1,500 Amp-turn. At the field test, magnetomotive force of 1,500 Amp-turn with current setting at 100 A and 15 turns of coils on both side of the welding zone is used, the field test shows that the force exerting on arc column disappears and there is no more deviation of arc column which conforms with the magnetic field simulation and justifies the idea generated by ARIZ.

7. Conclusions

The problem of low quality arc welding during pipeline maintenance due to residual magnetic field on the pipeline caused by MFL inspection device is systematically analyzed by deploying the method of function analysis and cause effect chains analysis to find the root causes of the problem, and ideal solution of which internal resources are utilized is searched for by using ARIZ. The potential solution with the idea of using magnetic field from welding current to counteract residual magnetic field on the pipeline is proposed, The welding engineer at the worksite can easily adjust the welding current and the number of turns to suit the optimal magnetomotive force with the simple formula as I*N = 1,500 Amp-turn. At the field test, magnetomotive force of 1,500 Amp-turn with current setting at 100 A and 15 turns of coils on both side of the welding zone is used, the result shows that the force exerting on arc column disappears and there is no more deviation of arc column which conforms with the magnetic field simulation and justifies the idea generated by ARIZ.

Although the solution in this paper is generated and designed to solve the problem on specific type and size of steel pipeline and with welding type as DCEP, the welding type of DCEN can also be applied and the solution can be easily extended to be used with other types and sizes of steel pipeline by finding the optimal magnetomotive force of the coil to counteract residual magnetic field on the pipeline.

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 PTT Exploration and Production Plc for their co-operation.

References

1. V.V. KOZLOV and I.V. TRET'YAKOV, "Using permanent magnets for preventing magnetic arc blow in repair of transmission gas pipelines," Welding International, Vol. 21 (6), pp. 460–462. 2007
2. Jose Hiram Espina Hernandez, Francisco Caleyo, Gabriela Lourdes Rueda Morales, Jose Manuel Hallen, Abraham Lopez Montenegro, and Eloy Perez Baruch, "Method provides welders new technique for avoiding arc blow," Oil & Gas Journal 270, pp. 158-166, 21 Dec, 2009
3. MILITARY PETROLEUM PIPELINE SYSTEMS. *Standards for pipeline welds*, [Online]. Available: http://www.globalsecurity.org/military/library/policy/army/fm/5-482/Appb.htm
4. Iouri Belski. *Improve your Thinking: Substance-Field Analysis.* TRIZ4U., 2007
5. G. Altshuller. (1985). *76 Standard Solutions*, translated and edited by Shinsuke Kuroswa. (2013) [Online]. Available: http://www.trizstudy.com/altshuller1988.html
6. Isak Bukhman. "Resources and Parameters of Resources," in *TRIZ Technology for Innovation*. Cubic Creativity Company, 20128, ch. 6, pp *187-210*.
7. Ellen Domb. (1998). *Using the Ideal Final Result to Define the Problem to Be Solved* [Online]. Available: http://www.triz-journal.com/archives/1998/06/d/index.htm
8. Kaplan, Stan. *An Introduction to TRIZ, the Russian Theory of Inventive Problem Solving.* Ideation International Inc., 1969
9. Altshuller Genrich. "40 Principles," in *TRIZ Keys to Technical Innovation*. translated and edited by Lev Shulyak and Steven Rodman. Worchester, Mass.: Technical Innovation Center, 1997, ch. *2*, pp *25-65*.
10. Jay Fisher. *Magnetic Property Measurement of Selected Pipeline Steel Specimens*, [Online]. Available: http://www.swri.org/4org/d18/nde/magprop.htm

Author (co-author) to contact: TriZit Benjaboonyazit, TriZit@gmail.com

TRIZfest 2014

The Strategy and Results of the Implementation of the TRIZ Methodology in Poland

S. Yatsunenko[1]; K. Józwa[1]; P. Karendał[1]; Z. Vintman[1]; P. Przytuła[2]; J. Boratyński[3]; A. Boratyńska-Sala[4]; I. Stańczak[5]

[1] *Aerfortis, 41-300 Dąbrowa Górnicza, Polska;*

[2] *Hive Project Management, 80-288 Gdańsk, Polska;*

[3] *ŚCITT, 25-323 Kielce, Polska;*

[4] *Politechnika Krakowska, 31-864 Kraków, Polska;*

[5] *Staropolska Szkoła Wyższa w Kielcach, 25-666 Kielce, Polska*

Abstract

The methodology of the Theory of Innovative Problem Solving (TRIZ) has already proven its worth and it is used worldwide. The TRIZ is widely used by the world's biggest enterprises to create innovative solutions. Many press articles written in Forbes Magazine or the ranking of the enterprises with the most patent applications held by The United States Patent and Trademark Office can be an excellent example of its growing importance. The companies such as IBM, Samsung, Intel, Canon etc. has already made the TRIZ integral part of their innovative, high technology business.

Recently we can observe growing popularity of the words such as "innovation" and "innovative" in Polish science and industry. Nearly every research or technological project, contains constantly repeated world - "innovative". However, does the process of creating something new is connected with the common use of the modern technologies and tools? Unfortunately not. Majority of the Polish specialists creating new technological inventions are still using obsolete tools and solutions established long before the TRIZ era.

What can be done in this situation? The elaboration will refer to the strategy and experiences of the implementation of the TRIZ in Polish science and industry. It will also present actions taken by the TRIZ-Poland initiative group:

1. Actions connected with the TRIZ training.

2. Practical application of the TRIZ solutions for the industry tasks.

3. Practical application of the TRIZ for scientific consulting.

4. Actions connected with the TRIZ-pedagogy.

Keywords: TRIZ introduction, implementation, strategy, Poland

Introduction

The objectives and assumptions of the Theory of Innovative Problem Solving[4] is widely unknown in Poland. Despite of TRIZ problem-solving potential, the vast majority of innovative tasks are solved unsatisfactorily, with ineffectively methods, such as, for example the trial and error method or brainstorming. It seems, that the rapidly growing interest in innovations in Poland is creating a perfect moment for implementation of TRIZ in common awareness. However, it is worth to emphasize that the process of the implementation of the TRIZ methodology is on its very early stage. Although the major changes, from chaotic phase to structuralized one has just begun, it is worth to point this early actions, which examples may be useful in promotion of TRIZ in other countries that never made use of this methodology. The "chaotic phase" or "unstructured phase", as we call it, is worth to mention from another reason. In many countries unfamiliar with TRIZ, without necessary structures and what is even more important, without skilled TRIZ trainers and teachers or basic literature it is nearly impossible to create resilient organization that will provide dispersion of TRIZ. Basing on recent Polish experiences, the grassroots movements that proceed in many individual actions should be considered as effective way to implement awareness of the Theory in the society. From this point of view, it is worth to describe this activities as an potential examples of what can be done to popularize and, as a final goal, implement TRIZ in countries with similar to Poland lack of necessary structures.

1. The beginnings of the popularisation of TRIZ in Poland: Interest in TRIZ - Pedagogy

Although the level of knowledge about TRIZ methodology is still very low in Poland, in the last few years, the group of enthusiasts have already undertaken some important actions to change the situation. As it was mentioned above, these early actions must be considered as uncoordinated ones, however they created vital opportunity to introduce TRIZ to the Polish society, especially youngsters, which can become effective users of the TRIZ methodology. Although the principles of the classic TRIZ are widely known in the "TRIZ Society", the foundations of TRIZ – Pedagogy, vital branch of the Theory, may be still unexplained, so it is worth to illuminate them. TRIZ – Pedagogy as it was mentioned, is playing important role in popularization of TRIZ in Poland.

The methodology of TRIZ-Pedagogy is oriented toward systematic learning of creative and responsible thinking, broad view on reality and on holistic perception of the world and knowledge. The main purpose of the TRIZ-Pedagogy technology, in the didactic and educational process, is to develop such mind attributes as: flexibility, mobility, searching activity, aspiration towards new, expression of the creative imagination and to form responsibility for own behaviour.

By the application of the methodology of TRIZ – Pedagogy in the curricular content of the educational units, we equip students in the ability of independent knowledge attainment - based on problem solving (mainly open-ended), we prepare them to operate in their grown-up life, we build the foundation of their future, and also we give them self-confidence in the present.

What is more, by the application of the methodology of TRIZ – Pedagogy in the teaching process, students can learn generalization, how to move from concrete things to abstract ones and conversely, the ability to find, in different objects and situations, the analogies and similar

[4] *The Theory of Innovative Problem Solving has its own English acronym – TIPS, however, authors of this paper decided to use the most popular and well-known Russian acronym – TRIZ.*

characteristics, and also ability to use the paradoxical logic along with the formal one. TRIZ is also developing, among the others, child imagination, ability of maverick thinking, and capability to focus attention on work in the pupil's group. As it was mentioned above, the methodology of TRIZ – Pedagogy may pay important role in popularization of TRIZ in Poland, and also may raise the future generation of TRIZ – users. The list of undertaken actions of popularization and implementation this branch of the Theory can be find below:

1.1. The training seminars in Moscow (Russia)

To provide the methodology of TRIZ – Pedagogy in our country, the Polish representatives of the higher educational units participate in three (36 hours each) training seminars in Moscow, organised by Anatol Aleksandrowicz Hin – TRIZ – Profi.

The list of participants and the agenda of training courses:

Jan Boratyński, Anna Boratyńska - Sala - 2008

Irena Stańczak, Sławomir Koziej - 2009

Jan Boratyński, Anna Boratyńska – Sala, Irena Stańczak, Sławomir Koziej - 2012

As it was mentioned, the lack of experienced and qualified trainers and teachers seems to be the most important factor that must be resolved at the first place. At the very beginning of implementation of TRIZ in any country without established structures it is essential to train domestic specialists. Although the detailed description in this article refers only to TRIZ – Pedagogy trainers, the "classic" TRIZ trainers has also been trained by specialists from Ukraine and Russia. Despite the early stage of the implementation the undertaken steps will facilitate wider TRIZ training in the future.

1.2. TRIZ – Pedagogy training for students of the Faculty of Pedagogy from Jan Kochanowski University in Kielce

After basic training of the first qualified teachers and stuff, it was decided to conduct the series of toll-free training for full-time course students of the 3rd year of the Division of Pre-school and Elementary Pedagogy, with therapeutic pedagogy specialization, realised by the Regional Centre for Innovation and Technology Transfer Ltd from Świętokrzyskie Voivodeship, in Kielce from 30th November, 2009 to 8th December, 2009 within the project: "Knowledge for business – the aid of the innovative entrepreneurship in Świętokrzyskie Region" (the TRIZ – Pedagogy training was held by Jan Boratyński and Irena Stańczak). The first "official" TRIZ lectures and training provided interest among the students and also spread the methodology of the Theory in the university environment. The first step of the implementation of TRIZ in the common awareness has been already taken.

1.3. Publication of Anatol Aleksandorwicz Hin's book: "Niezwykłe zagadki Kota Mądrali" ("Extraordinary riddles of Smart Cat")

In 2010, due to efforts of mgr inż. Jan Boratyński and favourable attitude of publishing house - Grupa Edukacyjna S.A. from Kielce, on the Polish publishing market appeared first book written in Polish for the students from lower primary school classes: Anatol Aleksandrowicz Hin's "*Niezwykłe zagadki Kota Mądrali*" (translated into 14 languages) – the book about the most famous cat. The translation from original Russian version and "cats poems" was made by Jan Boratyński – TRIZ Instructor and Chief Executive Officer of TRIZ Poland. The publication was another important step in popularization TRIZ in Poland. This time it was decided to introduce TRIZ among primary school classes. In the implementation process it is extremely important to remember about the future TRIZ users – the sooner we interest them in the Theory, the better innovators they will be in the future. The publication of "Niezywkłe zagadki Kota Mądrali" undoubtedly helped in this matter.

1.4. Publication of the book concerning TRIZ – Pedagogy

In 2013 came out first published in Poland elaboration about TRIZ – Pedagogy written by dr Irena Stańczak: "The Theory of Innovative Problem Solving at work with students from I-III grades of primary school (according to experimental studies)", Publishing House IMPULS, Krakow 2013 (number of pages 210), ISBN: 978-83-7850-440-5 that was another TRIZ popularization action.

In his review prof. zw dr hab. Stanisław Palka wrote: "Irena Stańczak undertook the elaboration of the problem of enrichment the theory and practice of the pre-school and elementary education – especially in development of cognitive activity, cognitive independence and creativity of pre-school and elementary students – by using the Theory of Innovative Problem Solving (TRIZ – Pedagogy). This area of pre-school and primary didactics, based on ideas of subjectivity, activity, active participation of the students in educational process, should be acknowledged as an important area of cognitive activity of researchers and educational practitioners (…)"[1]. The book written by Irena Stańczak not only was the first Polish action towards implementation of TRIZ teaching in elementary schools but also was the practical guideline to teachers and trainers how to use the methodology in effective preparation of the future TRIZ users.

2. The beginnings of the popularisation of TRIZ in Poland: Projects, business trainings and lectures

Although the TRIZ – Pedagogy played very important role in introducing TRIZ to Poland it was not the only one action that was conducted in that matter. Another important foundation of the implementation were coordinated projects and cycle of business trainings and lectures. The list of undertaken actions can be find below:

2.1. The implementation of the "TRIZ is changing the world" project – 2009

From the 2009 the status of implementation TRIZ in Poland began to change. Although it was still the very early stage, the taken actions started to be more coordinated and structured. As a results of this change with the cooperation of PARTNER SERVICE company from Krakow, ul. Rzemieślnicza 1, TIN: 683-131-10-13, represented by the owner – Marta Góra, the leader, creator and enforcer of the project, and PENTOMINO company, form Krakow, ul. Wł. Łokietka 236 B/B6, represented by the owner – Wacław Sala, the partner of the project, the "TRIZ is changing the world – the implementation of the innovative forms of children teaching in Małopolska Voivodeship" project, implemented from 1st January, 2009 to 31st December, 2009, within the European Social Fund: Human Capital Programme, Priority IX: Development of education and competencies in the regions, Action 9.1: Equalization of educational chances and providing high quality of educational services performed within the framework of the educational system (agreement no. UDA-POKL.09.01.02 -12-157/08-00) has been conducted. It was the first such a big action that include the whole Voivodeship. It was also excellent opportunity to exchange experiences and knowledge within TRIZ enthusiasts and promoters.

2.2. Realisation of the project „I am active – I will be an entrepreneur"

Another important event started in 2010. From 2010 to 2012 the Regional Centre for Innovation and Technology Transfer Ltd from Świętokrzyskie Voivodeship in Kielce realised a task with using TRIZ – Pedagogy in the project: “I am active – I will be an entrepreneur” within the Human Capital Programme, Priority II., Activity 2.2.1., PARP’s Strategic Plan no. 2/14/2010/POKL/01_03, time of the project realisation: from 1st October, 2010 to 31st March, 2012.

The Regional Centre published brochure entitled “I am active – I will be an entrepreneur”, which was not only teacher’s guide book, but also teaching resource for students, created by Jan Boratyński

As an effect of the project realisation, the publication edited by Irena Stańczak, entitled: “I am active – I will be an entrepreneur. Popularisation of Innovative Entrepreneurship Clubs and the methodology of TRIZ, methodical materials”, came out in 2012. ŚCITT, Kielce 2012 (208 pages), ISBN: 83-917786-4-9. The book is a summary of the Programme, contains various number of specific methods, created during realisation of the Programme and may be treated as a coursebook for teachers to introduce their students into the basics of entrepreneurship and management of own company. The realisation of the project, apart from wider popularisation of the TRIZ methodology, allowed to implement the basic principles of TRIZ to the industry and the entrepreneurs.

2.3. Programme “TRIZ Academy for business”

After the positive results of the previous project it was decided to conduct another programme that will establish the position of TRIZ in public awareness. From 2011 to 2012 the Programme “TRIZ Academy for business” aimed at small and medium entrepreneurships, also involving TRIZ Pedagogy, was realised within activity of the Regional Centre for Innovation and Technology Transfer Ltd from Świętokrzyskie Voivodeship. So called “advisory services”, which main task is the implementation of the methods of TRIZ Pedagogy, has been held not only at manufacturing companies, but also at companies that are involved in educational activities (private kindergartens and primary schools). Regardless of the fact, that the Programme is not completely finished yet, we can admit that it met up with common interest and support from the teachers and entrepreneurs, which was the main goal of the Programme.

2.4. Teaching, publishing and Internet activities

From 2009 to 2012 Jan Boratyński performed a wide number of 1,5 – 2-hour lectures for teacher groups: in Krakow (9-hour lecture), in Łodz, Katowice and Poznań – 2 and 1,5 hour. What is more, 30 persons from teachers group and employees from Educational Group in Kielce were trained in the 24-hours course for the 1st degree of TRIZ certification. According to the proposal made by Anatol Hin, teachers who intent to train other teachers about TRIZ should obtain 2nd degree certificate, based on separate principles created for TRIZ – pedagogues, they should also obtain, as a basis of their knowledge, 1st degree of TRIZ certification, based on overall principles.

In all, for the last 4 years, there have been conducted 25 lectures, that encouraged to acquaint with the methodology of TRIZ – Pedagogy. It is widely agreed, that effective implementation of TRIZ methodology is impossible to provide without certified domestic specialists, that will be future members of the structured TRIZ society within the country. Even though the first attempts of effective training for future TRIZ trainers was not structuralized and did not have widely spread scientific support, they were massive success. For the first time 1st degree specialists were trained in Poland, what is more, they were trained by Polish trainers. Another important step for the implementation of TRIZ in Poland has been taken.

What is more, as a part of popularization of TRIZ and TRIZ – Pedagogy, Jan Boratyński and his daughter – Anna Boratyńska – Sala are running a website: www.triz-innowacje.pl.

The topic of TRIZ – Pedagogy is absorbing more and more time of Jan Boratyński's writing activity. From 2009 to 2011, at "Hejnał pedagogiczny" monthly magazine from Małopolska Voivodeship. 8 papers about TRIZ - Pedagogy have been published. At the same time, form January 2005, at "Klub wynalazców" – column in the "Młody Technik" monthly magazine, Jan Boratyński is publishing materials from the basis of TRIZ for primary schools and high schools students (113 papers altogether). The publishing activity is also one of the essential steps of the effective popularisation. With the necessary background such as papers, books and web activity more people may be inquisitive about the TRIZ methodology and may try to get more information about it by themselves. Curiosity, on the other hand, is the first step for the more scientifically attempt to TRIZ.

2.5. TRIZ Training for entrepreneurs and industrial employees

From the beginning of 2014, after the positive results of the past projects and the first introduction of TRIZ as an effective problem-solving method, the Aerfortis company, started series of training programmes about TRIZ methodology for entrepreneurs and industrial employees. Although it is still too early to make any conclusions about the efficiency of the training, building on the growing interest from enterprises and the commitment of the participants of the courses, we can assume, that this kind of popularisation of TRIZ in Poland may pay important role in the future. The rapidly growing number of companies that are interesting in such training proved that the first phase of introducing TRIZ to the Polish society has ended. What is more, during the course, Aerfortis company is conducting a survey among the participants, which results will help to improve the training programme and adjust it to the needs of the participants. The teaching programme created by the Aerfortis company may be also considered as the first fully structuralized action with the standardisation of the methods in Poland. We can also clearly conclude that the "chaotic phase" is finished and it is being substituted by the structuralized one.

3. The results of the implementation of TRIZ methodology in Poland: summary of the first phase and potential strategy for other countries

As it was concluded above, the first phase of the implementation of TRIZ methodology in Poland has been finished. Although, the very beginnings of the long popularization process was rather chaotic and uncoordinated, the later actions conducted by more than single enthusiasts seemed to be more organized, even though, as it was mentioned, they were still provided without strong association. Growing interest on training programs, especially among entrepreneurs and industry employees, proved that chosen methods of the introduction were successful and effective. For countries such as Poland, where there are no basic structures and the level of TRIZ knowledge is extremely low, the strategy of single, uncoordinated at the beginnings, actions that changed into more organised programmes seems to be the best way for achieve the main goal, which is the implementation of TRIZ to common awareness. As a conclusion it is worth to mention, that the described actions can be classified as a potential guideline for other, similar to Poland countries. The potential strategy of the implementation of TRIZ methodology is described below:

1. The training of the future TRIZ introducers (abroad or by the foreign specialists).

2. Publishing activity – papers, books, internet articles, translations of the foreign TRIZ coursebooks.

2.1. As a parallel action – introducing TRIZ to school teachers and academic teachers.

3. Introductory courses for the school and academic teachers.

3.1. Certification courses for the school and academic teachers.

4. After the training of the domestic specialists – basic courses for pupils and students.

5. Introduction of TRIZ to entrepreneurs and industrial companies.

5.1. First business courses and TRIZ training programmes for industry.

6. End of the first phase – knowledge of TRIZ and its opportunities that it gives is spread among teachers and entrepreneurs; first domestic trainers are prepared; first companies offer effective TRIZ methodology training.

6.1. The beginning of the second, structuralized phase - the domestic TRIZ association.

4. The structured phrase: Polish TRIZ Association

As a part of cooperation with Regional Centre for Innovation and Technology Transfer Ltd from Świętokrzyskie Voivodeship, some key activities have been conducted to create the Polish TRIZ Association, which should facilitate the promotion of TRIZ in Poland. The statue of the Foundation has been already agreed, there are only few formalities left, and at the beginning of September the official Polish TRIZ Association will become a reality. There have been also scheduled or already conducted some other activities for the implementation TRIZ in Poland. Apart from the trainings for entrepreneurs and industry employees, solving industrial tasks and scientific consulting for industries held by the Aerforits company, the future professional TRIZ trainers and consultants have been trained at the same time. What is more, within the Association, it was planned to translate and publish TRIZ coursebooks and, what is even more important, advanced guidelines of the use of TRIZ methodology in innovative problem solutions. Another important action, within the Polish TRIZ Association, was decision to create extensive TRIZ vocabulary with exact translation of the Russian acronyms to the Polish language (for example: TRIZ – Teoria Rozwiązywania Innowacyjnych Zadań). The last long-term activity within the Association is to implement TRIZ semester courses in polytechnic institutes and universities.

Despite of the fact, that the organised and fully structured process of the introducing TRIZ to Poland has already begun, the observed level of interest shows that its common and widespread implementation has highest chances to succeed.

References

1. Stańczak I. “Teoria Rozwiązywania Innowacyjnych Zadań w pracy z uczniem klas I-III szkoły podstawowej (w świetle badań eksperymentalnych)”. Kraków, Oficyna wydawnicza IMPULS, 2013.

Author (co-author) to contact: Sergey Yatsunenko, sergey.yatsunenko@aerfortis.pl

TRIZfest 2014

TRIZ Evolutionary Approach: Main Points and Implementations

Victor D.Berdonosov[a], Elena V. Redkolis[b]

[a]*Komsomolsk-on-Amur State Technical University, Komsomolsk-on-Amur, 681024, Russia*

[b]*Komsomolsk-on-Amur State Technical University, Komsomolsk-on-Amur, 681000, Russia*

Abstract

There are a lot of evolution models, but the most interesting among them is the model of the TRIZ-evolution. According to this model, artificial systems satisfy increasing demands of the society and develop when they overcome contradictions with TRIZ tools.

The TRIZ-evolutionary approach is applied in any considered field of human activity. Initial objects can be either engineering systems or knowledge systems of mathematics, programming, and etc. In this case TRIZ-evolutionary maps must be created for every filed. These maps are revealed a tree of states (implementations) of the initial object which are connected with contradictions and TRIZ-tools that solved these contradictions.

The TRIZ-evolutionary approach provides an efficient controlling tool of the artificial systems evolution suitable for forecasting their development. In particular, the TRIZ-evolutionary approach helps to define what contradictions were solved and has not been solved in the provided system. Thus if “forgotten” contradictions are solved then system ideality will increase respectively.

In the report we give the TRIZ-evolutionary maps and propose the forecast of some artificial systems development based on the TRIZ-evolutionary approach.

Keywords: TRIZ-evolutionary, artificial systems, systems or knowledge, forecast.

1. Introduction

The theory of evolution is perceived subconsciously as evolution of biological species. At the present moment there are a lot of theories and models of biological species evolution [1, 2]. Among which there is modern evolutionary synthesis based on Ch. Darwin’s and G. Mendel’s [3] works; the model of molecular evolution that is known as the theory of neutrality; etc.

But artificial objects also develop [4, 5] It is of great interest to learn evolution of these objects. Unfortunately the theory of evolution is mostly evaluating but not forecasting issue. As for our opinion the predictive issue is the most important in investigation of artificial systems. It means that if it is known the evolution trend line of an object then it is possible to predict the following implementation of this object. TRIZ may cover not only technical objects but artificial objects too. Based on TRIZ it is possible to create a model of evolution that has both qualification and predictive issues. The present article is dedicated to description of the above-mentioned model.

But this model can be used for artificial systems only. An initial object exists in any evolution model, as for fractal model it is a pattern. And an artificial system is an initial object of the TRIZ-evolution model. Transformation of the artificial system happens under moving power according to a set of rules.

2. Model of TRIZ Evolution

The TRIZ evolutionary model coincides ideologically with the fractal model though does not copy it. Benoît B. Mandelbrot [6] was a founder of fractal investigations. He described development (evolution) of fractal objects in the following way. There exists an initial oject (a pattern) of free complexity. It can be either lines joined together or a multi-figure object. Then the pattern starts developping according to definite rules. Each element of the pattern is replaced with its tranformed copy. Transformation here is scaling, shortening up to the size of replacing element and rotating if it is required. This is the way of the first iteration of the fractal object.

The same way is used for following iterations. Fig. 1 shows the sequence of iterations: zero (the pattern), the third, the fifth and the eighth.

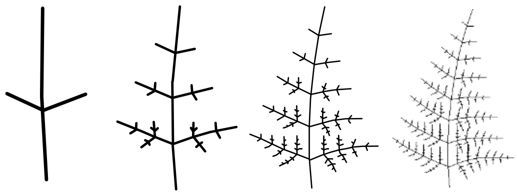


Fig. 1. A fractal model of fern

The quantity of iterations is not limited. If a definite pattern is chosen and a number of iterations are done then the fractal model is similar in appearance to a real object. This is the model of a fern in our example.
Though ferns are simple plants they have more difficult patterns and more complicated rules of “transition” from one iteration to another one then in the example given above.

There exist the following basic terms of a fractal model of evolution: the pattern (the initial object) is an object based on which the construction of a fractal object starts. Rules of transformation (the rules of construction) are the rules according to which we get an iteration based on the previous one. Moreover there is one more term here – this is resources or space for fractal objects where the object takes place. The resources for real fern are nutrients, space, and ultra-violent (sunlight).

The TRIZ evolutionary model uses the same set of terms. A pattern is an initial artificial (technical) object which is a starting point for development of a family of objects.

It is necessary to clarify here what the word “technical” means. The Greek word “techne” was understood widely: from skills of craftsmen to proficiency in the high art. The word “techne” related to different fields: farming and hunting, sailing and medical treatment, weaving and gun smithing, performing arts, etc. [7]. Technical knowledge is an interlink between experience and theoretical knowledge. Technical knowledge is used for manufacturing and designing. In technical knowledge manufacturing process includes the stages of mental designing of an object, creating the project and design engineering. 17th Century was a period of technological revolutions and changes in manufactures; and in Western Europe the Latin word "technica ars" (art of skillful manufacture) transfers to the term "technique" in French and then to the term "technic" in German. This term becomes special. Now it means a set of resources, procedures and measures which relate to manufacturing especially work equipment and machines. Thus technologies develop and the concept content also changes. In our report we will include in the concept "technique" both a device (a machine) and a computer program that will control this device (machine), programming languages and knowledge by virtue of which the devices have been created and developed.

The next concept is "rules of construction" by virtue of which the initial pattern develops passing from one iteration into another. Here it is necessary to add the following comments. At first this passage does not happen on impulse but under the action of contradictions which appear as iteration between increasing requirements of the society and limited capacity of an object. The rules of construction of the TRIZ evolutionary models are TRIZ tools: methods of technical and physical contradictions resolution, a tool part of Laws of technical systems development, standards of sufield transformations, etc [8, 9].

To show a family of technical objects we will take programming paradigms as an example [10]. The initial object is coding. Coding is a system of machine language codes which is interpreted for the certain microchip. This is the first and the most elementary paradigm of programming.

Of course this paradigm consists of a lot of contradictions. We will consider only one of them. Difficulty of programming tasks increase constantly. At a moment a programmer is not able to write and to debug software which contains thousands of bits. By present it is a very small program. For example, a program of calculating factorial function consists of not less than one thousand and half bits. Here the contradiction appears: if difficulty of a task increases then the time of programming increases unacceptably. To solve the appeared contradiction it can be used an inventive principle "Copying" and "Merging". We will consider concrete solutions that eliminate the contradiction. The first solution is following: using the "Copying" principle the terms "cell location" and "argument" are changed with the term "operand". The second solution is following: using the "Merging" principle homogeneous machine codes are combined on mnemonic commands.

By virtue of solving contradictions a new resource appears that is possibility to transform machine codes into mnemonic code. As a result, a new programming paradigm appears, that is assembling (see Fig. 2).

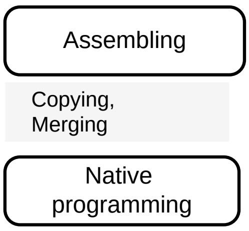


Fig. 2. The first iteration of programming paradigm

So TRIZ evolutionary model includes an initial technical object, rules of "construction" which are TRIZ tools and resource restrictions.

3. TRIZ evolutionary approach

Now we are going to consider the TRIZ evolutionary approach based on the example of an artificial system – a paradigm of object-oriented programming [11]. The evolution of any artificial system can be presented in a form of tree: the base element is a root and other implementations of the artificial system grow from this root. The base element for object-oriented programming is Simula-67, the first in the world object-oriented programming language that was developed in 1960s (see Fig. 3).

All implementations of the artificial system must have the same system attributes as the base element. The tree "grows" according to the model of TRIZ evolution. At first the contradictions are defined which have not been solved by the latest implementation (it is the base element at the first iteration). For example, the grave disadvantage of the Simula-67 language was absence of debugging tools: time is lost to find the causes of mistakes. So if difficulty of software increases then the time of debugging increases unacceptably. Moreover other contradictions can be found: if the size of programming code increases then software reliability decreases unacceptably; if the quantity of hardware platforms increases then the program efficiency decreases unacceptably.

Then TRIZ tools are found which were used to solve contradictions during developing of the initial object and the implementation of the artificial system with solved contradiction is described. The resources and principles that were used for contradictions solving should be considered. And the resources that appeared during usage of TRIZ tools should also be described. We shall come back to our example (see Fig. 3). A part of contradictions was solved in the Smalltalk language with the principle "Transition to a Supersystem": software development environment was created. It had a user interface and provided debugging facilities.

With the "Intermediary" principle the sequence of program compilation was changed: programs are transferred to an intermediate representation by means of byte-codes and compiled into a machine language code in service. It allows initializing them at different hardware platforms. In the C++ language it became possible to process error conditions with the "Self-service" inventive principle. This process is used to monitor program behavior to errors.

A tool "Design by contract" was worked out with the "Preliminary action" inventive principle in the Eiffel language. This tool allowed assigning different types of conditions (contracts) which are being checked during work of the program.

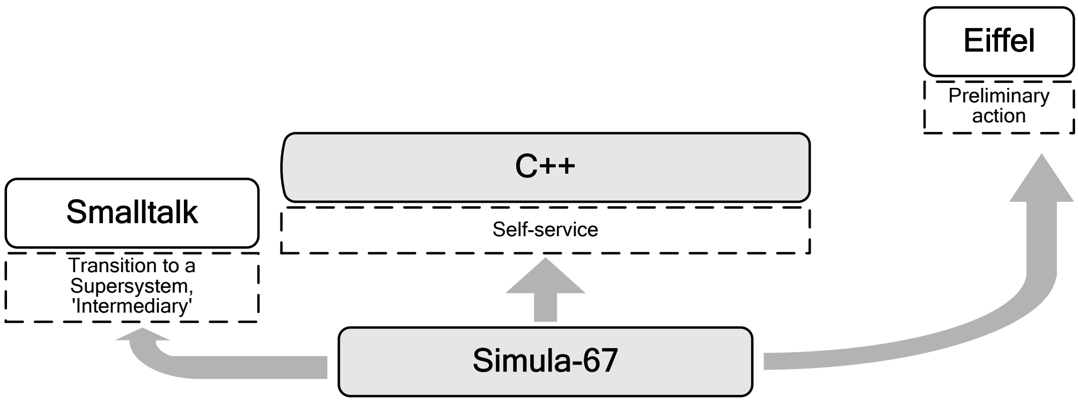


Fig. 3. The first steps of growing object-oriented program languages

It should be noted that in reality fragments of the tree can grow linearly if the contradiction is solved with one tool, or branch out if different contradictions are solved with different tools. In last case the line evolution transforms into tree-type one (see Fig. 4). As a result the TRIZ evolutionary approach in analyzing of artificial systems allows not only systematizing the idea of its evolution but also opening new implementations.

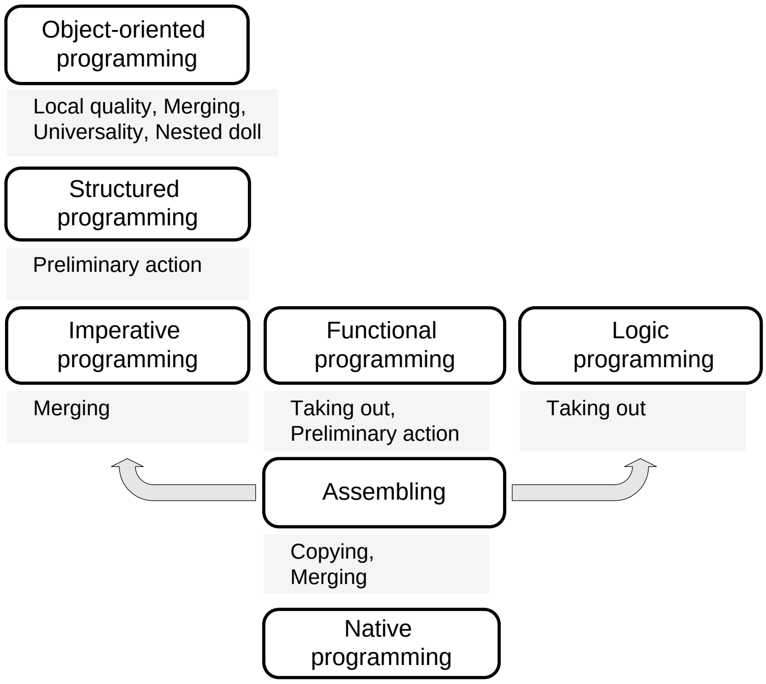


Fig. 4. Tree-type evolution of programming paradigm [10]

So there are following advantages of the TRIZ evolutionary approach:

1. It helps to systematize the idea of artificial systems development in past, present and future based on TRIZ tools in order to forecast development of artificial systems.

2. It allows investigating (opening) new implementations of artificial systems.

3. It provides an integrated base for knowledge systematization in any field either practical (for example, TRIZ evolution of a car or a plane) or theoretical one (for example, TRIZ evolution of numerical methods, or TRIZ evolution of programming tools, etc.).

4. It allows sorting system implementations according to the rate of ideality increase at the stage of analysis and investigation of new system implementations.

4. Implementation of the TRIZ evolutionary approach

We will consider more or less full implementation of the TRIZ evolutionary approach by the example of numerical methods [12]. Numerical methods are defined as methods of approximate solution of typical mathematical problems, which come to performing of finite quantity of elementary number operations. These methods are various [5-8]: linear algebraic equation systems solution, equations and nonlinear algebraic equation systems solution, numerical integration and differentiation, solution of Cauchy problem for ordinary differential equation, etc. In addition there is a list of specific methods for almost every above-mentioned field of application (see Fig. 5). Due to the area limits a part of methods is shown with numbers. The description of these numbers is presented in the paper [13].

Such a great number of poorly systematized knowledge (methods) does not allow studying all numerical methods sufficiently in order to choose the most suitable one and for education process too.

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 solving techniques presented by the corresponding objects. Therefore it makes sense to consider TRIZ evolutionary map of a model of and a family of TRIZ evolutionary maps of numerical methods with regard to each model.

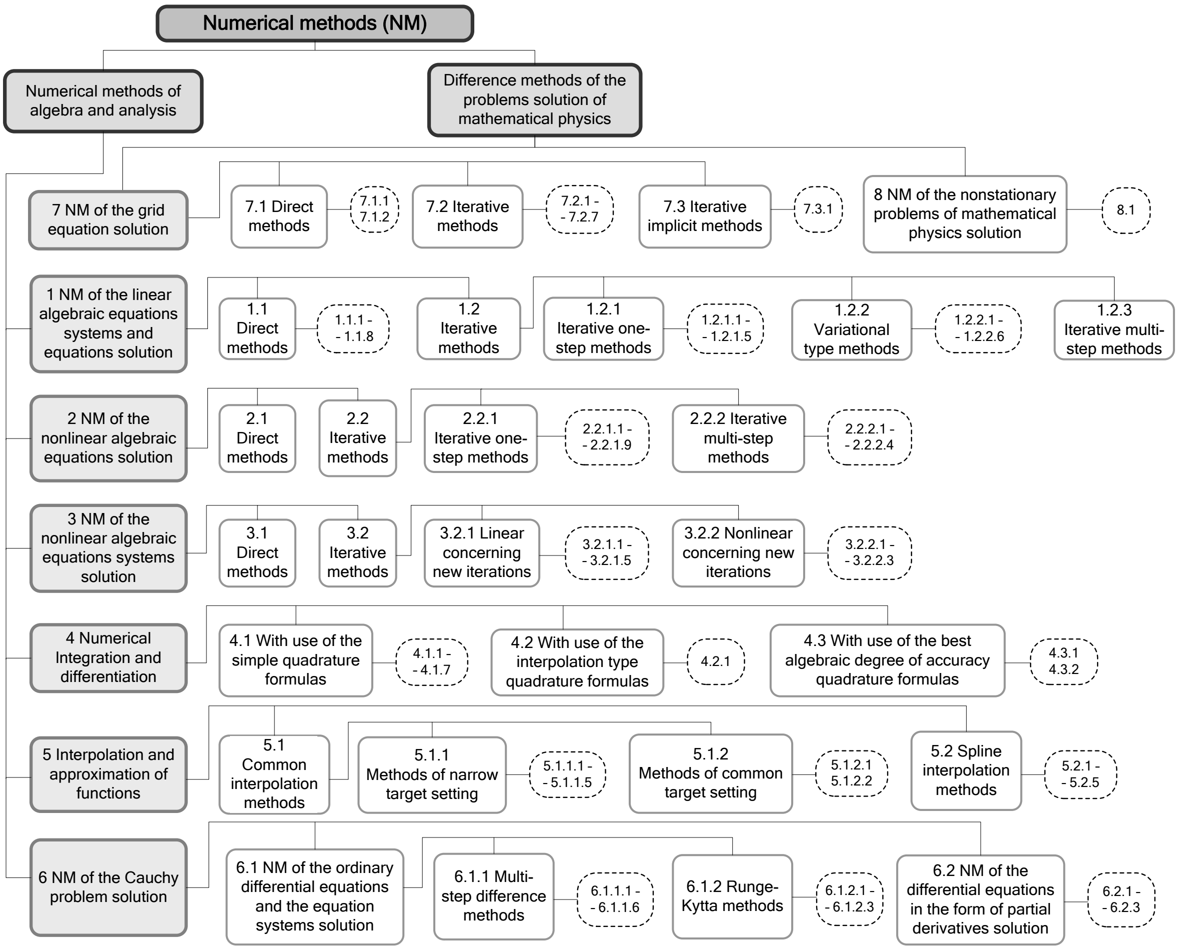


Fig. 5. Numerical methods structure

The evolution process of models is associated with increase of mathematical models adequacy to their real physical prototype. For example, behavior of different nature macro models systems is described by linear and nonlinear algebraic equations systems, behavior of micro models is described by differential equations systems and behavior of micro models of distributed systems is described by differential equations in the form of partial derivatives. The evolution process of numerical methods is concerned with increase of ideality of existing models realization. For example, at first direct numerical methods were used for linear algebraic equations solution, then iterative one-step methods and iterative multi-step methods followed and etc. Whereupon the ideality criteria consist of accuracy, convergence, number of arithmetic operations, etc.

We will consider in detail the line of development of description models of real physical that is we will consider the development of mathematical models which describe objects of the real world more and more adequately.

The first models were linear equation systems. But scientists found out that if an acceptable region of variants that are included in the equation system is wide enough then test data and estimated data will be considerably different. This situation appears because the World is not linear in principle and linearization can be performed in a small range. To approximate estimated data to test ones a wide acceptable region was divided into some small parts and parameters of linear equitation systems were defined separately. It led to the great volume of calculations.

That is a contradiction appeared: increase of closeness of agreement of linear equation systems solution to test data led to UNACCEPTABLE increase of volume of calculations. To solve this contradiction it was used a method “transition to another dimension” where “another dimension” means transition to the category of non-linear functions (equations).

Transition to non-linear equations allowed to describe 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 processes referring to different sub-systems take place. 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 solving non-linear equations of different sub-systems not connected with each other significant mistakes appear. That is a contradiction appears again which can be solved by the “Combination” principle. Technical object starts to be described with the system of non-linear equations, etc.

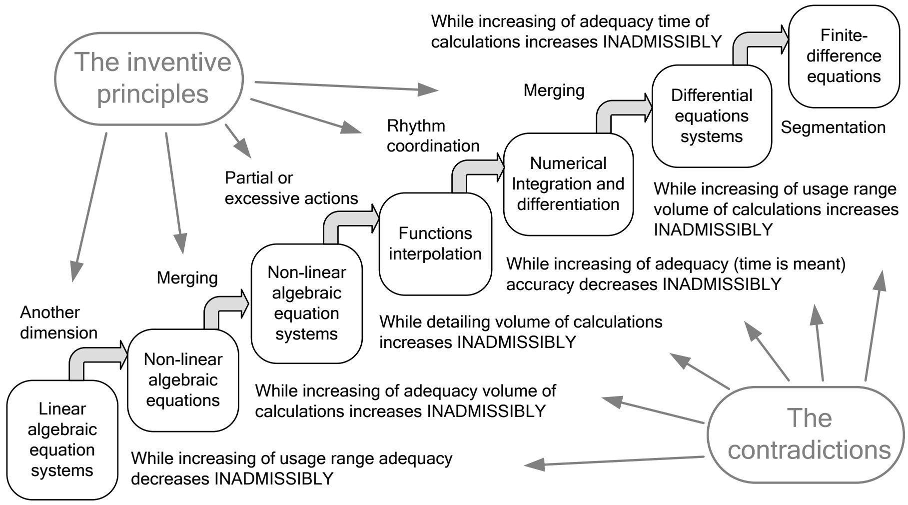


Fig. 6. Evolution of the objects description

While solving contradictions that appear during development of numerical methods we will receive a line of evolution of description models of real physical objects (see Fig. 6). The same ways was used to consider the lines of evolution of problem solving techniques.

We will consider the first model, methods of solution of linear algebraic equations. Let it is required to increase method's rate of convergence (to decrease number of final arithmetic calculations). The rate of convergence is limited by the number of arithmetic calculations for direct and counter motion (time of performing direct and counter motions). Time of motions performing depends directly on a type (a structure) and a degree of a matrix: the solution will be found faster if the degree is less. The case with structure of a matrix is similar, because the solution will be found faster if the structure is simpler [14]. Therefore, to decrease the number of final arithmetic calculations it is necessary to make a mathematical model of the real world that contains a matrix of a medium degree (<100), or, and that is better, of a small degree which angle minors shall be non-zero. But such mathematical model does not describe fully the behavior of systems macromodels.

This mathematical model does not completely describe the behavior of macromodels of different nature systems. A contradiction appears: while increasing the rate of convergence of the Gauss Method, the number of the real world objects macromodels decreases UNACCEPTABLY. To solve this contradiction it is proposed to use the “Feedback” principle.

Numerical Simple iteration method was used for solving. If we analyze all other solutions methods of linear algebraic equation systems we will receive the line TRIZ evolutionary map (see Fig. 7).

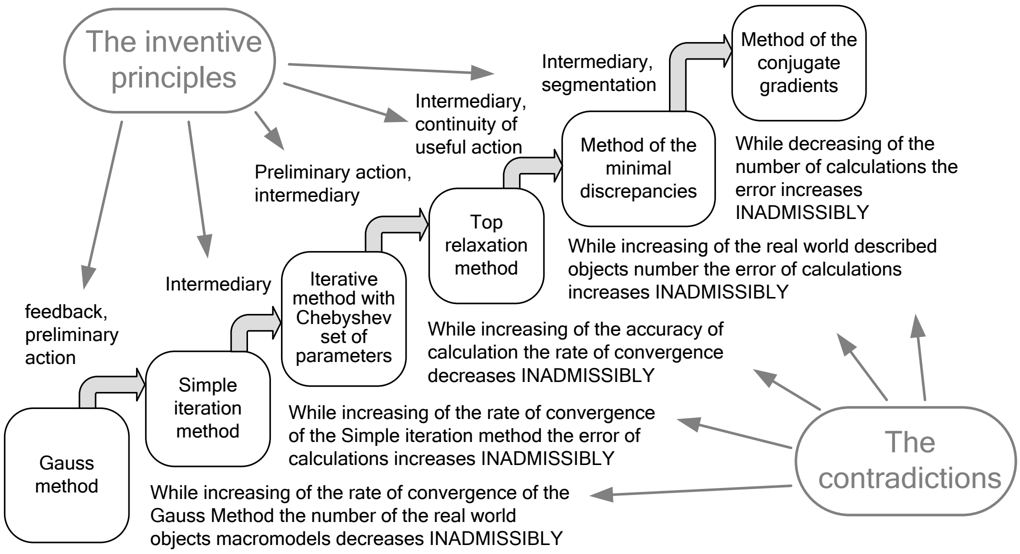


Fig. 7. Evolution of the methods of the linear algebraic equations system solution

After all basic lines of method development have been being studied it is possible to create the TRIZ evolutionary map of numerical methods (see Fig. 8).

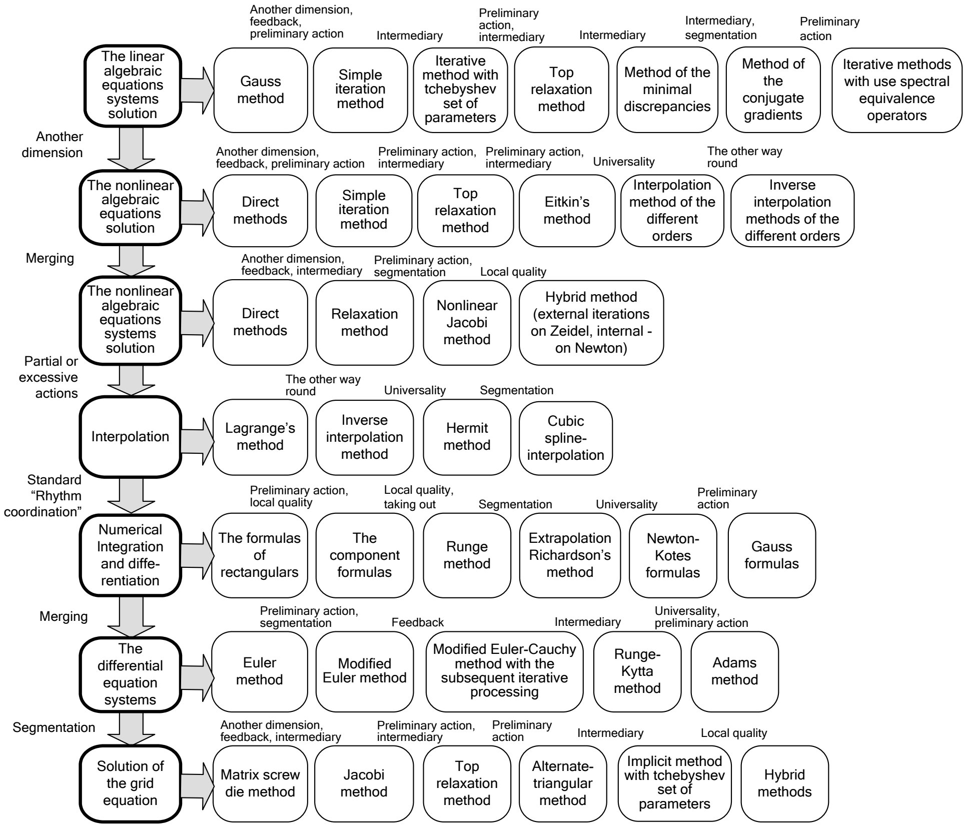


Fig. 8. TRIZ evolutionary map of numerical methods

If we compare the created TRIZ evolutionary map (see Fig. 8) and the initial classification we will see that:

1. It was created a simple and demonstrative presentation of the structure of numerical methods that can be used in education if there is limited time to study a great volume of material;

2. Development of numerical methods as other artificial systems (for example, programming paradigms) is subordinated to clear logic of increasing ideality;

3. Quantity of “basic” numerical methods that are required to learn for solving different problems were reduced due to excluding methods that have similar ideality.

5. Conclusions

According to investigations TRIZ is the excellent tool for systematization of a wide range of artificial systems. Even such non-traditional fields for TRIZ as mathematics and programming can be systematized. The TRIZ evolutionary map appears as a result of this systematization. The basic TRIZ trend lines are presented in the map: increasing ideality through contradictions solution, roll out-roll in.

If TRIZ is used as a foundation for analysis of different artificial systems (from technical to knowledge systems) the efficiency of education process will increase. The education process is aimed at learning of main types and objective laws of definite artificial systems. Besides, if the TRIZ evolutionary approach is used then engineering quality increases at stages of analysis and proposals (investigations) of new implementations of technical systems.

Totally, it can be concluded that usage of the TRIZ evolutionary approach allows intensifying essentially the study of selected knowledge areas by systematization of knowledge not only at the level of contradictions resolution, but also at the level of contradictions formulation.

The way of thinking "from a contradiction to a contradiction" allows systematizing information about some problem, formalizing this problem, selecting parameters which should be improved or worsened, and formulating it clearly that speed up the search of solution. Sometimes the correct question is already the best answer.

References

1. Jukes T.H. and Cantor C.R. “Evolution of Protein Molecules”. New York: Academic Press, 1969. pp. 21-132.

2. Kishino H., Hasegawa M. “Evaluation of the maximum likelihood estimate of the evolutionary tree topologies from DNA sequence data, and the branching order in hominoidea”. Journal of Molecular Evolution 29 (2), 1989. pp. 170-179.

3. Mendel G. “Versuche uber Pflanzen-Hybriden”. Verhandlungen des naturforschenden Vereins in Brünn, t. IV, 1866. pp. 3-47.

4. Capra F. “Web of Life: A New Scientific Understanding of Living Systems”. New York: Anchor Books, 1996.

5. Shpakovsky N. “Trees of evolution. The analysis of engineering information and generation of new ideas”. Moscow: TRIZ-profi, 2006. ISBN 5-9348-6048-8.

6. Mandelbrot B. “The Fractal Geometry of Nature”. Freeman, New York, 1983.

7. Oxfordreference.com, website Retrieved 2011-12-03, 1995. ISBN 0-1986-6132-0.

8. Altshuller G. “Creativity As An Exact Science: The Theory of the Solution of Inventive Problems”. Translated by Anthony Williams. Gordon and Breach Science Publishers, 1984.

9. Zlotin B., Zusman A., Altshuller G., Philatov V. “Tools of classical TRIZ”. Ideation International Inc., 1999.

10. Berdonosov V., Sycheva T. “TRIZ-evolution of Programming System”. Proceedings of the ETRIA TRIZ Future Conference, Dublin, 2-4 November 2011. Published by Institute of Technology Tallaght, 2011. ISBN 978-0-9551218-2-1.

11. Berdonosov V., Zhivotoa A., Sycheva T. “TRIZ evolution of the Object-Oriented Programming Languages”. Proceedings of the ETRIA TRIZ Future Conference, Lisbon, 24-26 October 2012. Published by University Nova de Lisboa, 2012. ISBN 978-989-95683-1-0.

12. Korn G., Korn T., “Mathematical Handbook for scientists and engineers”. McGRAW-HILL Book company, Inc. New York, Toronto, London, 1961.

13. Berdonosov V., Redkolis E. “TRIZ-Fractality of mathematics”. Procedia Engineering, 2011. Vol. 09. pp. 461-472.

14. “Numerical methods. Manual for technical schools”. Edited by Danilina N. and others. Moscow: The Higher School, 1976.

Author (co-author) to contact: Victor D. Berdonosov, berd1946@gmail.ru

TRIZfest 2014

TRIZ for Waste Elimination on a "Lean Production" Environment

Christian M. Thurnes[a], Frank Zeihsel[b], Frank Hallfell[b]

[a] *University of Applied Sciences Kaiserslautern, Amerikastraße 1, 66482 Zweibrücken, Germany*

[b] *Synnovating GmbH, Mozartstraße 25, 67655 Kaiserslautern, Germany*

Abstract

An essential component for the further dissemination of TRIZ may be the fit with widely spread principles and programs. The combination of Lean-production and TRIZ seems to be easy but in real life the most promising way is to identify blind spots in Lean and to apply TRIZ exactly there.

To continue works of the authors in this area, this paper shows how to add TRIZ to one of these blind spots, the so called "necessary waste". It describes the formulation of physical contradictions out of "necessary waste" as the foundation to eliminate this kind of waste with TRIZ-tools completely whereby in Lean it is only subject of reduction.

Keywords: TRIZ, Lean Production, Waste.

1. Relevance of "Lean Production" as a field of TRIZ application or integration

1.1. Production Management: a profitable field for TRIZ application

Production management and especially problem solving in the area of manufacturing engineering and manufacturing logistics is a field, where TRIZ can demonstrate its powerful concepts very imposing. Solving problems regarding production utilities and manufacturing or production processes have been topics for TRIZ-application since many years. A lot of examples demonstrate this in famous books. These examples are dealing with different production process issues from different branches and in various technological fields; such examples can be found among others in the works of G. Altshuller, see e.g. [1], [2]. There are several TRIZ-publications that also consider aspects of production management more detailed, like e. g. the concept for waste reduction of Voluslav Mitrofanov [3].

The area of production management is very useful to show up the power of improvement methods – and in our case TRIZ. In this surrounding, problems usually have to be solved in a short time, because real expenses or missed revenues are counted second by second. This is very different to problem solving in product development, where the return of the solved problem pays back a long time after the action of problem solving. Therefore TRIZ-application in production management is an outstanding chance, to demonstrate the advantages of TRIZ in companies, by achieving easily perceptible savings – the pecuniary success of using TRIZ-tools in this surrounding is measured immediately and so there is a quantitative prove of concept. And this money-related prove might be a very good recommendation to use TRIZ also for other topics, like product development or intellectual property management and so on.

1.2. Lean production: the most disseminated production paradigm

Lean Production is still the most present concept in production management. Many production companies around the world try to follow the concepts, collected and developed by famous managers and practitioners like Taiichi Ohno [4] or Shigeo Shingo [5]. There are some TRIZ-publications, that try to match TRIZ and specific approaches of the Lean Production (e. g. [6]). And on the other hand, there are some Lean-books that refer to several TRIZ-tools. So for example Mascitelli recommends TRIZ for some steps in the lean product development process [7] and Bicheno and Holweg connect the lean term “value” directly with thoughts regarding the ideal final result from the perspective of customers [8], like mentioned by Mann [9]. But in real life, TRIZ-enthusiasts in many companies are surprised, that the Lean-enthusiasts ordinary don’t accept TRIZ-tools and the related approaches. This seems to be amazing, because problem solving is one of the core elements of Lean Production (see e. g. [10], [11]).

Recently Thurnes and Zeihsel (also authors of this paper) tried to discover the real-life issues that cause the small dissemination of TRIZ-methodology in Lean-Production companies. They presented different concepts for promising TRIZ-usage in a Lean Production environment [12]. Their identified preferred way to integrate Lean Production and TRIZ in a Lean environment, is to find the blind spots in the Lean-methodology and to integrate TRIZ-concepts exactly at this points.

The Objective of this paper is to explain the approach for integrating TRIZ in the treatment of so called “necessary waste” as one specific aspect of lightening a Lean blind spot with TRIZ.

2. Core elements of the approach

2.1. Waste as term of art in Lean production

Waste (or muda) is a term of art in the lean lingo. The elimination or at least reduction of waste is the core element of any Lean Production concept. Thereby waste is specified very strictly. In one dimension, waste is divided into seven classical categories [8], [10]:

- Overproduction
- Waiting
- Motions
- Transporting
- Overprocessing (or inappropriate processing)
- Inventory
- Defects

Besides this classical distinction, more recent definitions added further categories. In our research, we will keep this seven categories because they are origin and known by every lean professional around the world. But not every activity that belongs to the seven categories is waste principled. Only if the activity does not contribute to the value of the good, it has really to be treated as waste. So for example, “transporting” may not be waste, when a shipping company is doing it. But besides exceptions like this, any activity in production that is not adding value to the product is waste and can be categorized using the seven classical wastes.

In our study another perspective on waste in the Lean terminology is essential. This distinction judges activities by ranking their necessity [8], [10]:

- value add (necessary)
- necessary waste (also: Muda type 1, non value adding, necessary non value adding)
- avoidable waste (also: Muda type 2, avoidable non value adding, obvious waste)

From this point of view, all activities of a production process or within a production facility can be categorized first in: value add, necessary waste or avoidable waste. And after that, the activities in the waste categories can be specified into the seven categories mentioned above.

2.2. Issues of elimination waste in Lean production with TRIZ

Now the elimination of avoidable waste and the reduction of necessary waste can be addressed as tasks for problem solving. The Lean Production toolset offers a lot of simple tools especially to work on the elimination of avoidable waste. Thereby some principles are difficult to realize with classical TRIZ applications: "[…] solving at the place where the problem occurs, solving towards an immediate implementation, solving with continuous reflection and towards continuous improvement with small steps. [...] Besides these management principles some basic rules of Lean Management may trouble the application of TRIZ tools, especially the emphasis on the doing (so called operational excellence)" [12].

So, even if TRIZ is very useful to solve all kinds of problems arising from the observation of waste, in real-life there is no need for Lean-practitioners to use TRIZ to eliminate avoidable waste – there are sufficient tools to solve this kind of problem in most cases in their own toolbox. The more doctrinal lean tools are focusing this "low hanging fruits". So the lean-tools to eliminate avoidable waste are wide-spread and there is no chance (and no reason for) to change these tools in practice. Actually, the toolset for more complex tasks like the reduction of necessary waste is neither strongly defined nor common among many people – so there is a much better chance to install inventive problem solving sessions with TRIZ applications as "special lean tool" for reducing or even eliminating "necessary" waste. [12]

So, the more promising concept is to concentrate on using TRIZ for treating the "necessary" waste.

2.3. Applied TRIZ tools and principles

The approach shown below refers to some basic TRIZ tools and principles. This encompasses mainly the topics of physical contradictions and peripheral the 40 inventive principles. These elements of classical TRIZ are described in fundamental works like [1], [2], [12] and some recent interpretations of the inventive principles towards their meaning in a Lean production environment [14].

3. Treating "necessary" waste with TRIZ

The treatment of necessary waste with TRIZ is promising, because:

- necessary waste by definition provides contradictions
- the Lean-toolset ordinary just strives to reduce (not to eliminate) this kind of waste – because it seems not to be possible to solve the contradictions

Necessary waste is comprising activities, that do not add value to the good, but are (or better seem to be) necessary to fulfill the given task.

"For example the transportation of a good from goods receiving to goods outwards seems to be necessary for a production company but the customer doesn't want to pay for it – so this transportation is necessary waste. If the same good during the production process is transported several times between different places back and forth inside the facility there may be some avoidable waste in this transportation processes that could be eliminated easily." [12]

A closer view on the first part of this example above illustrates the abilities of TRIZ usage in this case. The classical view judges the transportation from goods receiving to goods outwards as necessary waste: *It is waste (category waste of transportation), so we don't want it, but it is necessary, so let's reduce it by removing the avoidable parts of the transportation.*

The TRIZ-perspective on this problem offers a lot of abstract solutions, for example using the separation principles. Or let's have a view on the Inventive Principles (see e. g. [13]): 13 "Do it in reverse" and 15 "Dynamics" directly offer solutions to eliminate this "necessary" waste instead of reducing it by tradeoff.

From a methodological point of view, necessary waste provides contradictions by definition. Dealing with necessary waste means that a previous observation has shown, for instance, that the good must be transported from point A to point B. On the other hand transportation is waste. This can be formulated as a contradiction: the good should be moved from A to B because of the production flow and should not to be moved, because transportation is waste. In the same way, activities in each category of necessary waste can be defined as a contradiction.

So, attacking necessary waste targets a field that is essential (even if it has not the first priority for the lean people) and where organizational embedding and lean-toolset usually are not defined very well. Because by default any description of a necessary waste represents a contradiction, there might be TRIZ-sessions to work on resolving contradictions like the TRIZ-enthusiasts ever did (see e. g. [14], [15]), engaging the lean people to work on necessary waste.

An additional support for TRIZ users can be found in the "Lean-Operators for the 40 inventive principles" [16] – these operators provide specific lean-interpretations of the inventive principles and hints for their application in a lean environment.

4. Exemplary contradictions found in necessary waste

This chapter shows some generic contradictions that can be found

- in the classical **Lean 7 categories** of waste (see [8], [10]) by
- focusing on **necessary** waste.

With this two rules in mind, all this contradictions can be build, following the scheme:

- <activity (necessary waste)>
- SHOULD NOT BE DONE, because it doesn't add value (<explanation>)
- AND SHOULD BE DONE because of <reason for perceived necessity>

Hereby the *<activity (necessary waste)>* ordinary should be found by lean-specialists as a result of their waste-analysis and be declared as "necessary waste". If they declare it as "necessary", they are able to explain the necessity, what automatically leads to the case-specific definition of the *<reason for perceived necessity>*. In this manner the examples below do not cover comprehensively the complete topics but illustrate the usage.

4.1. Waste of Overproduction

In Lean-thinking, overproduction is the most serious kind of waste. Overproduction leads to all other kinds of waste and is the root-cause for many disadvantages in production management. Basically, overproduction means, that goods are produced without a need in this point of time. Maybe they are produced to early or even completely in spec. Very often overproduction is the result of using free capacities to do at least something, instead of doing nothing – naturally, this is an example for avoidable waste. But there are other reasons for overproduction that may appear as necessary waste.

Example C01:

- <producing 100 parts>
- SHOULD NOT BE DONE, because it doesn't add value (<*only 60 parts ordered*>)
- AND SHOULD BE DONE because of <*load of the machine is 100 parts*>

Example C02:

- <producing gas A>
- SHOULD NOT BE DONE, because it doesn't add value (<*only gas B ordered*>)
- AND SHOULD BE DONE because of <joint-product production generates gas B only when generating gas A>

4.2. Waste of Waiting

Waiting means, that a resource like a human being is doing nothing, because something necessary to proceed didn't happen. The logical impact is that the resource is doing nothing, but ordinary is paid for doing something. But in Lean-thinking the most serious influence of waiting is the disturbance of flow. In the range of this study, the formulation of contradiction has to concentrate of only the activities that are classified as **necessary** waiting waste.

Example C03:

- <delay processing of product A>
- SHOULD NOT BE DONE, because it doesn't add value (<*flow is stagnating, resource doing nothing*>)
- AND SHOULD BE DONE because of <paint from previous process has to dry>

4.3. Waste of Motions

Ordinary the consumer of goods is not willing to pay for the fact that the employees at the factory have to move a lot while producing the goods. So most of the motions are not adding value to the product (exceptions are the motions connected with a value adding activity, like tighten a screw). Motion waste generally is caused by the working procedures and/or by parameters of the layout and shape of materials, work stations, machines and facilities. Ordinary one can find a lot of avoidable motion waste in production processes – the activities that are declared as being **necessary** motion waste are very often connected with parameters of the layout, that aren't easily to change. For the following example, an operator has to stretch to observe a material flow that is located behind his machine –the machine shape as well as the layout may not reasonably be changed.

Example C04:

- <operator stretching body>

- SHOULD NOT BE DONE, because it doesn't add value (<motion takes time, lowers quality and concentration, provokes errors, burdens operator>)
- AND SHOULD BE DONE because of <*observation of another process behind the machine*>

4.4. Waste of Transporting

The previous chapter already discussed an example for this kind of waste, illustrating the difference between avoidable and necessary waste of transporting. Drawbacks of transporting are the resources needed for transport itself and all kinds of material handling related with transportation. But transportation also increases the risk of quality issues and complex transportation aggravates the information flow, which is very important for a continuous material flow. In this waste category the most found activities may be avoidable waste. Like above, the reasons to declare activities as necessary have their roots in aspects of the setting and the surrounding that are not allowed to be changed.

Example C05:

- <transporting boom segments of cranes from paint shop to testing area>
- SHOULD NOT BE DONE, because it doesn't add value (<*transport is not paid, risk of transport loss*>)
- AND SHOULD BE DONE because of <testing assembly needs available space of the testing area>

4.5. Waste of Overprocessing

The waste of overprocessing (or inappropriate processing) describes the excessive fulfillment of a function, using oversized procedures or machines as well as doing things that are absolutely not needed or ordered – for example the grinding of a surface, that hasn't got any functional or optical relevance and that is just done because of the mood of the designers to design "proper" things. Naturally this is an avoidable waste.

In Lean-thinking "big" machines and procedures are not only under suspect to disturb the flow of materials and to be not very flexible, but also to provoke overprocessing. Regarding the necessity (that has to be declared, when one is looking for necessary waste), very often parameters of machines or processes show some potentials for the formulation of contradictions. Let's have a look at a washing machine that cleans complex metal parts from grease – the process could be cheaper, because only some specific sections of the parts have to be cleaned, but the machine encompasses the complete part.

Example C06:

- <cleaning some sections of metal parts from grease>
- SHOULD NOT BE DONE, because it doesn't add value (<cleaning of this sections lowers efficiency and is not needed>)
- AND SHOULD BE DONE because of <washing machine stores the whole part, that also has sections that must be cleaned>

4.6. Waste of Inventory

Inventory is a kind of waste that also fosters other wastes. Form this point of view it is similar to the waste of overproduction. In fact some kind of inventory is the result of overproduction. But besides finished goods, inventory may also exist in the form of raw materials or work in process. Accumulation of inventory increases the throughput time and slows down the material flow. Also the information flow is more complicated, when there are more objects that generate or need information. Besides some avoidable reasons for inventory, inventory seems to be necessary, to protect the production system from variations. So some “necessary” inventory buffers variation in the process and some inventory works as safety buffer regarding disturbances of supply or orders.

Example C07:

- <safety buffer of 200 pieces part A>
- SHOULD NOT BE DONE, because it doesn’t add value (<increases work in process, costs, risk for defects, transporting, motion>)
- AND SHOULD BE DONE because of <demand varies and supplier ships only once a week>

4.7. Waste of Defects

The waste of defects is self-explaining: defects cost money, material and other resources but ordinary are not paid by the customer. In Lean-thinking there are further reasons, why defects have to be avoided. Many lean concepts like one-piece-flow and Kanban only work with good pieces. The harm of defective parts in such a surrounding is much bigger than just the costs of the defective part itself. Concepts like Jidoka and Poka-Yoke are trying to filter out the avoidable waste of defects. In an existing production environment, maybe some defects are declared as “necessary”, because the corresponding conditions can not be changed – e. g. a SMD mounting machine produces not only good parts, but can not be replaced or improved because of the costs.

Example C08:

- <processing of 5% defective SMD-boards>
- SHOULD NOT BE DONE, because it doesn’t add value (<*Kanban-circles will collapse or have to be oversized*>)
- AND SHOULD BE DONE because of <SMD-mounting device has 5 % rejects>

5. Re-formulation of the contradictions found in necessary waste

The formulation procedure above leads to generic formulations of physical contradictions in form of the “Hamlet-contradiction: to be or not to be”. The authors described the topic this way, to illustrate the logic of creating contradictions out of the necessary wastes of the Lean-production-concepts.

To resolve the contradictions, they may be re-formulated like shown in the example below, whereas this is not the core topic of this paper. In discussion with the authors, Robert Adunka suggested to reformulate the appearing contradictions to find more specified physical parameters for the contradictions. E.g. a re-formulation of the example C01:

- <producing 100 parts>
- SHOULD NOT BE DONE, because it doesn’t add value (<*only 60 parts ordered*>)
- AND SHOULD BE DONE because of <*load of the machine is 100 parts*>

could lead to the parameter “part count” in the contradiction:

- <part count>

- SHOULD BE <60>, because <*only 60 parts ordered*>)
- AND SHOULD BE <100>, because of <*load of the machine is 100 parts*>

A re-formulation like this may be part of the process of working with the contradictions, that will follow the procedure of the formulation of the generic contradictions.

6. Conclusion

For the dissemination of an useful methodology like TRIZ, it's not only important to have the right tools – it is also important to make them fit with the mindset and the methodological initial situation of the target user group.

Based on some preliminary work the treatment of so called "necessary wastes" has been identified as a very suitable chance to implement TRIZ-thinking and –tools in a Lean Production environment. This is because:

- exactly in this point original lean methodology has some blind spots and
- necessary waste constitutes contradictions by itself, what is nearly ideal to apply TRIZ.

The paper just focused on the seven classical waste categories. Other categorizations may be used in the same manner, as long as the emphasis stays on the necessary waste (not the avoidable waste).

The thoughts show above provide the motif and the tool, to integrate TRIZ in Lean procedures. This combination opens up the chance to convince more and more Lean practitioners regarding the power of TRIZ in attacking Muda-Type 1. This in turn may be the enabler to exploit a huge potential for further dissemination of TRIZ into the Lean community.

References

1 Altshuller, G.S., 1979: Creativity as an exact scienc, Moscow, Sovietskoe ratio, Translated by Williams, A. 1984, Crc Pr Inc, 1979, ISBN 978-0677212302

2 Altshuller, G.S., 1996: And suddenly the Inventor appeared, Technical Innovation Center Inc., Translated by Shulyak, L., 1996 ISBN_0-9640740-2-8

3 Mitrofanov, V.V., 1998: «OT TexHonornHecKoro 6pai<a AO HaynHoro OTKpbiTna» ("From manufacturing waste to scientific discovery"), St. Petersburg: TRIZ Association of St. Petersburg, 1998, ISBN 5-7997-0090-2

4 Ohno, T.; Rosen, C.B., 1988: The Toyota Production System: Beyond Large-scale Production, Productivity Press, 1988, ISBN 978-0915299140

5 Shingo, S.; Dillon, A.P., 1985: A Revolution in Manufacturing: The Smed System: Single-minute Exchange of Die System, Productivity Press, Shopfloor Series, 1985, ISBN 978-0915299034

6 Ikovenko, S.; Bradley, J., 2005: TRIZ as a Lean Thinking Tool. TRIZ Journal, 02.2005.

7 Mascitelli, R. 2011: Mastering Lean Product Development – A Practical, Event-Driven Process for Maximizing Speed, Profits, and Quality. Quality Books, Inc., 2011, ISBN 13-978-0-9662697-4-1

8 Bicheno, J.; Holweg, M., 2009: The Lean Toolbox: The Essential Guide to Lean Transformation, Picsie Books, 4th edition, 2009, ISBN 978-0954124458

9 Mann, D., 2004: Hands on Systematic Innovation: for Business and Management, Edward Gaskell Publishers, 2004, ISBN 978-1898546733

10 Liker, J., 2004: The Toyota Way: Fourteen Management Principles from the World's Greatest Manufacturer, Mcgraw-Hill Professional, 2004, ISBN 978-0071392310

11 Rother, M., 2009: Toyota Kata: Managing People for Improvement, Adaptiveness and Superior Results; Mcgraw-Hill Professional, 2009, ISBN 978-0071635233

12 Thurnes, C.M.; Zeihsel, F., 2013: Lean-TRIZ instead of TRIZ Lean, in: Proceedings of the 13th Etria World TRIZ Future Conference 2013, Paris.

13 Altshuller, G.S., 1999: The Innovation Algorithm, TRIZ, Systematic Innovation and Technical Creativity, Technical Innovation Center, Translated by Shulyak, L.; Rodman, S., 1999, ISBN 978-0964074040

14 Zlotin, B.; Zusman, A.; Altshuller, G.; Philatov, V., 1999: TOOLS OF CLASSICAL TRIZ. Ideation International Inc., ISBN 1928747027

15 Hentschel, C.; Gundlach, C.; Nähler, H.T., 2010: TRIZ – Innovation mit System, 2010, ISBN 978-3446423336

16 Thurnes, C.M.: 2014: Lean-Operatoren als Ausprägungen der 40 Innovativen Prinzipien. In: OPINNOMETH – Schriften des Kompetenzzentrums für Operational Excellence und Innovationsmethodik, Heft 1/2014, p. 4-19, www.opinnometh.de, ISSN 2199-0301

Author (co-author) to contact: Frank Hallffell, hallfell@synnovating.com

TRIZfest 2014

TRIZ Propagation Strategies in Chevron Holdings Ltd.

Georgi Severinets*, Ming Chen**

** Chevron Holdings Ltd, Nanjing; 2111106; China*
*** Chevron Holdings Ltd, Nanjing; 2111106; China*

Abstract

Chervon specializes in researching, developing, manufacturing, testing, sales, and after-sale services for electric power tools and related product categories. It has a well-earned reputation for continual innovation and dedicated pursuit of quality. TRIZ is used as an innovation tool. TRIZ gave us a great economic effect and an opportunity to apply for dozens of patents by solving manufacturing process and product problems. In this paper we show you TRIZ propagation strategies in the Chervon in terms of people, process, and product. Speaking of TRIZ people, we have outside TRIZ expert and Chinese experts certified by MATRIZ. Besides, we set up TRIZ process to give Chervon employees an incentive to learn and use TRIZ. As a result, we were able to produce competitive products in the world. This paper will be a good reference to any company who want to use TRIZ efficiently.

Keywords: TRIZ, company, efficiently, education.

1. Introduction

According to our experience and experiences of other companies in TRIZ application to the industry, TRIZ works very well.

Since these process takes long time to learn and utilize TRIZ more efficiently, the great concern has to be taken for developing and implementing TRIZ propagation strategies in our company.

Only by taking the right people and process, we can get the right product.

In this paper, we would like to describe what we have done to propagate and utilize TRIZ in our company CHERVON in terms of people, process, and product.

2. CHERVON (China) Trading Co., Ltd.and TRIZ

CHERVON started as an international trading company in 1993.

Now Chervon Holdings Ltd. specializes in researching, developing, manufacturing, testing, sales, and after-sale services for electric power tools and related product categories. It has a well-earned reputation for continual innovation and dedicated pursuit of quality.

CHERVON Company recognized the need for innovation more strongly than before.

CHERVON is one of the top-ten providers of power tools worldwide.

CHERVON has more than 5000 employees around the world.

- CHERVON in mainland China: CHERVON (China) Trading Co., Ltd.—the sales, service and support center;
- Nanjing CHERVON Industry Co., Ltd.—the manufacturing base;

- CHERVON R&D Center is established in 2007, further enhanced our capability of research and innovation. R&D Center—the organization's innovation base for product and corporate development.

More than 300 highly qualified technical professionals from China, U.S., Europe and Japan work together in the CHERVON R&D Center.

More than a half of R & D engineers dedicate their efforts to development of seven categories of power tools, offering customers rich choices from the level of OPP, MPP to HPP

Questions that need to be answered today:

1. How can a company stay active in a competitive market?

2. How can we transfer the "eureka moment“ to "independent & consistent innovation” in the process of product innovation?

In spite of huge sales and profit in business, CHERVON Company has a sense of crisis that we have been a fast follower and we cannot survive anymore in this position. Instead of leading the industry by developing innovative products, we have followed fast what the leading companies had developed. Top management pointed out this and asked employees not to be a fast follower, but to be an innovative leader.

While Six Sigma, QFD, DFMEA, DOE and Other innovative methodology goes for finding the best trade-off solutions, TRIZ goes for solution contradiction.

We think TRIZ in CHERVON is placed at the end of infant stage in S-curve and is moving to development stage.

3. People and process

When a company wants to do innovation, the first thing is who is in charge of the innovation. In case of methodology like TRIZ, which takes a long time to comprehend, it is more important. TRIZ people include outside TRIZ experts and inside employees. Outside TRIZ experts, Belarus and China are highly experienced in TRIZ project and training.

Inside employees are mostly engineers who have at least three-year engineering experience and are interested in TRIZ.

CHERVON invited several outside TRIZ experts, who have more than ten-year TRIZ experience and specialty in other fields.

To conduct real industry projects and obtain good results, specialty in other specific field as well as TRIZ experience is of great importance.

First of all, they trained a group of inside employees on trial. This group of inside employees formed a TRIZ study group.

Since 2008, CHERVON has launched four times TRIZ training in the RD centre, IWINT had been invited to train the first two rounds and the nearer two rounds were trained by internal TRIZ teachers.

Photo: The photo of management team of Chervon and class of first training team.

Outside TRIZ expert started a pilot TRIZ project with a small success. A small success in this stage is very important. After this stage, Outside TRIZ expert joined joint TRIZ projects by outside experts and inside employees. In addition to joint TRIZ project, they were also involved in training inside employees. One of our goals is to let a lot of inside employees conduct TRIZ projects by themselves.

4. Training with projects:

All trainees were trained to use the theories and methods helping to think and solve the specific problems in their projects. This enabled the students to deeply understand the power of TRIZ theory, strengthen the understanding of TRIZ and at the same time solve the problem of real projects. What a perfect one stone for three birds.

We present some results of our long and painstaking training work.

The first training:

- 30 participants, five months of training
- 30 projects, generated 123 ideas to solve the problem.
- 7 project issues were resolved, and another two projects achieved stage progress, total accounting for 30%.
- five patents were generated.
- 20 students passed ITC second level certification.

The second Training:

- 28 participants, six months training.
- 28 topics generated 139 ideas to solve the problem.
- 10 project issues were resolved, and the other six projects achieved progress, total accounting for 57%.
- 7 patent application.
- 5 students passed ITC the third level certification, becoming the company's internal TRIZ instructor.

Table 1: Topic Results

Triz training	Three (2011)	Four (2012-2013)
Issues of project	25	22
Generated ideas	160	143
The number of patents	10	13
Applied Project	1	5
Items to be applied	5	10
Technical reserves	7	3
Efficiency	52%	82%

Meanwhile: CHERVON R&D Center has 8 teachers gain the 3rd level of International MATRIZ qualifications.

5. Prospects and Development

The establishment of internal TRIZ system in company:

- Leader of TRIZ : General Manager personally in charge, taking the responsible of planning the systematic construction of TRIZ to promote innovation, according to the Group's strategic planning.
- TRIZ Association: One foreign TRIZ experts (MATRIZ Level 4) with eight internal TRIZ experts (MATRIZ Level 3), responsible for training and guiding staff, consulting on problems, certifying internal ability, researching on innovation, lunching innovative information and organize the annual innovative activities.
- TRIZ team and members: 6 TRIZ group of 105 members, distributed in various departments of R & D centers, responsible for researching pre-developing projects and solving technical problems, participating in annual TRIZ Innovation competition and information exchange project .
- TRIZ training being one of the training class in the training system in RD center,
- Establish internal certification system.
- TRIZ training being one of the training class in the training system in RD center, serving as the required subject to engineers and senior engineers. Materials prepared by internal lecturers.
- Meanwhile, establish the internal TRIZ certification system, 82 students of the second round training had passed the company's TRIZ II level certification.
- TRIZ activities carried out inside

a) TRIZ training.
b) TRIZ Certification
c) TRIZ project selection
d) TRIZ project contest
e) TRIZ Innovation Forum
f) TRIZ consulting on research projects

6. Conclusion

CHERVON made the first step toward TRIZ application to the industry successfully and is to make another step.

Experience outside TRIZ experts contributed to the successful first step by conducting TRIZ projects well and training inside employees.

The processes for TRIZ project and education have been developed on the basis of our experience and culture.

What we will do in the future:

1. We will continue to strengthen of TRIZ team and training process.
2. We will continue to apply and use of TRIZ in various stages of product development.
3. We will explore the use of mixed methods TRIZ and QFD, DFMEA, DOE, 6-SIGMA, serve to solve problem in the development stage

References

1. TRIZ and innovation culture at Samsung Electro-Mechanics Company.; SeHo Cheong; Vasily A. Lenyashin; Alexander T. Kynin; Naum B. Feygenson; YongKwan Lee; Seungheon Han (Samsung Electro-Mechanics Company, Corporate R&D Institute, Solution Creation Group); The Fourth TRIZ Symposium in Japan, 2008

2. TRIZ application process at Samsung Electronics.; Author: Jun-Young Lee, Sung-Wook Kang.
3. How to make TRIZ work in your organization?; Philips Innovation Services – Industry Consulting Christoph Dobrusskin
4. Denis Cavallucci, nathalie Gartister, (2002), “About difficulties to diffuse TRIZ within a corporate structure“, ETRIA world Conference TRIZ Future 2002.
5. Ellen Domb, James Kowalick, (1997), “How to Bring TRIZ into your organization“, TRIZ Journal.
6. TRIZ入门及实践：赵敏等 著.; 丛 书 名：技术创新方法培训丛书出 版 社：科学出版社ISBN：9787030242167出版时间：2009-03-01版

Author (co-author) to contact: Georgi Severinets, g.severinets@gmail.com

TRIZfest 2014

TRIZ Tools for Solving IT Problems

Vladimir Petrov[a], Sergei Sereda[b], Ph.D.

[a] *Raanana, 6/4 Klauzner St. 43367,* Israel

[b] *Moscow, 35/64 N. Krasnoselskaya St. 105066, Russia*

Abstract

Information technology (IT) has reached a very high level of complexity and, in fact, has become a critical part of human activity. Its development, however, has ceased to be *extensive*, which means that in order to develop a technology it is not enough merely to add a microcontroller or computer with software. Moore's Law[5] is at the end of its validity; however, no methodology for parallel programming has yet been generated. Developers of hardware and software are facing difficult problems that need to be solved very quickly and at a high level. In this context it is no longer enough to possess special knowledge, experience and intuition, but requires a developed and time-tested method for solving complex problems. According to the authors, the best methodology for solving complex problems is TRIZ. TRIZ is able to solve the accumulated contradictions, to provide IT with *intensive* development without hindering extensive development, and to use existing resources effectively to solve actual problems.

In this regard, the authors consider this subject to be very topical.

Proposals to adapt selected TRIZ tools for solving problems in the IT field are presented in this paper.

Keywords: TRIZ, ARIZ, contradictions, ways to eliminate contradictions, information technology (IT).

1. Publication review

The first known work on using TRIZ in IT is that of Kevin C. Rea [2]. Rea further elaborates on this topic in another paper [3]. The Laws of Technical Systems Evolution applied to computer operating systems were reviewed in [22].

These works, in our view, are mainly about the formulation of the problem. Altshuller's Inventive Principles [1] were adapted to IT by Darrell Mann [4, 7], Umakant Mishra [6, 11], Michael Rubin [9] and Vladimir Petrov [12, 16].

An adaptation of Su-Field Analysis was done by M. Rubin [10] and V. Petrov [12, 17-19].

The laws of technical systems development were adapted to IT by V. Petrov [21].

Some other aspects of adapting TRIZ tools for IT are contained in the works of U. Mishra [13-15, 20].

These changes have made it easier to use TRIZ in IT, but they are only in the initial stage of adapting TRIZ for IT.

---

[5] IDF: Gordon Moore Predicts End of Moore's Law (Again) // Wired,

http://www.wired.com/2007/09/idf-gordon-mo-1.

In this paper we make the next step in adapting TRIZ tools for solving IT problems. We also show examples of adapting the logic of ARIZ [5] and Inventive Principles [16] for solving IT problems.

2. Using the Logic of ARIZ

Problem 1. Program operation.

Problem condition

How to make the algorithm itself faster?

Problem analysis

Administrative contradiction (AC).

AC: A

The program needs to work faster (**A**).

Technical contradiction (TC).

TC: A – anti-B

Making the program **work faster** (**A**) can be done by reducing the number of computational operations, but this requires storing intermediate calculation results, which **increases the amount of RAM** (**anti-B**) used.

Short TC:

Making the **program work faster** (**A**) leads to **an increase in the amount of RAM** used (**anti-B**).

Ideal Final Result (IFR).

IFR: A, B

Make the program **work faster** (**A**) without **increasing** requirements to **the amount of RAM** (**B**).

Physical contradiction (PC).

PC: P→A, anti-P→B

*There should be **few (P)** computational operations to* make the program work **faster** (**A**), *and there should be **many (anti-P)** operations so as not to increase* requirements to **the amount of RAM** (**B**).

<u>Physical contradiction 1</u> (PC$_1$).

PC$_1$: P→P$_1$, anti-P→anti-P$_1$

*The operations should be **<u>large</u>*** (**P$_1$**), *that is, more universal, so that there are **few*** (**P**) *of them; and they should be **<u>small</u>*** (**anti-P$_1$**) *so that there are **many*** (**anti-P**) *of them.*

And so:

PC: The computational operations should be ***few (P)*** and ***many (anti-P)***.

PC$_1$: The operations should be ***<u>large</u>*** (**P$_1$**) and ***<u>small</u>*** (**anti-P$_1$**).

Solution.

Separate contradictory properties:

In Space.

1) Use an external system memory (examples: architecture of "client-server" with dedicated database server; sound and video duplex transmission using "peer-to-peer" (P2P) network – Skype; video broadcasting using P2P network – Torrent TV).

2) Use the computing power of an external system (examples: architecture of "client-server" with dedicated application server; distributed attack on ciphers – breaking RSA[6]; distributed computing project SETI[7]).

3) Combine items 1) and 2).

In Time.

1) Aggregate computations; break the algorithm into steps, each of which is implemented by a separate program. When they are connected in the pipeline, a systemic effect appears.

2) Switch from single-threaded to multi-threaded implementation of the algorithm with parallel execution of the multiple-thread program by the CPU in time-sharing mode. This can also be applied to the use of phase transitions and to the use of internal system resources.

3) Use virtual memory: save "foreign" blocks of RAM to the disk and release them for the current program to use, and then recover them from the disk when returning control to the "owner".

In Structure.

Use reduced instruction set computing (RISC[8]) architecture for implementing algorithms.

Use recursion (mathematical effect) with multiple uses of the same memory areas; for example, software implementation of matrix determinant expansion by minors.

By Condition.

Create conditions when some of the computational operations are not needed (examples: software implemented solutions for problems with preset parameters; software implemented solutions for defined subclasses of problems).

Combining subsystem functions (**a new way to solve a PC** – introduced by the authors).

Embed an "expedited" program in another program or use the subprogram of another program so that by eliminating redundant computing operations the overall memory-size requirements are reduced and (or) the program's speed increases.

Adding an additional resource (**a new way to solve a PC** – introduced by the authors).

Use additional digital or analog processors (examples: floating-point unit – FPU, graphics processing unit – GPU, a fuzzy logic processor, hardware encryption card, speech recognition card).

---

[6] **RSA** (cryptosystem) is one of the first practicable public-key cryptosystems and is widely used for secure data transmission. In such a cryptosystem, the encryption key is public and differs from the decryption key, which is kept secret. – From Wikipedia.

[7] **SETI** (*Search for Extraterrestrial Intelligence*) is the collective name for a number of activities undertaken to search for intelligent extraterrestrial life. SETI projects use scientific methods in this search. – From Wikipedia.

[8] **RISC** is a CPU design strategy based on the insight that simplified (as opposed to complex) instructions can provide higher performance if this simplicity enables much faster execution of each instruction. – From Wikipedia.

Use internal system resources (if an additional resource has already been introduced in the system earlier).

1) Do not use CPU to perform computing operations; for example, use CUDA[9] technology to use the HPC graphics coprocessor.

2) Do not use RAM for storing intermediate results of calculations; for example, use video memory.

3. Using Inventive Principles

Problem 2.Protecting programs accessible to multiple users.

Problem condition

A rather complex and unique program is stored as an executable file in the network and is, therefore, accessible to other staff of the Institute. The results of this program (the source and the results of calculations) were also stored this way.

A password was not set for fear it would be cracked.

How to restrict access to a program so that only the author can use it?

Problem analysis

There is a technical contradiction (TC) between **protecting information** by entering a password, and **unauthorized access** if the password is disclosed.

This contradiction corresponds to Altshuller's parameters:

24. Loss of Information – 30. External Harm Affects the Object.

This contradiction is resolved by Inventive Principles **22, 10, 1**:

We can choose some of Altshuller's other parameters:

24. Loss of Information – 32. Ease of Manufacture (Inventive Principles: **27, 22**).

30. External Harm Affects the Object– 32. Ease of Manufacture (Inventive Principles: **24, 2**).

Altshuller's Matrix proposed the following Inventive Principles:

1. Segmentation.

2. Taking out.

4. Asymmetry.

10. Preliminary action.

22. 'Blessing in disguise'.

24. Intermediary.

27. Cheap short-living objects.

Solution.

1. Segmentation. Divide the file into independent parts.

---

[9] **CUDA** (Compute Unified Device Architecture) is a parallel computing platform and programming model created by NVIDIA and implemented by the graphics processing units (GPUs) that they produce. – From Wikipedia.

1.1. Segment input parameters: each parameter can be set individually or in parts. If only the author of the program knows the segmentation level of the parameters, then no one else will be able to use the program. Security will be additionally enhanced by keeping the boundary conditions confidential.

1.2. Segment the resulting data: each result can be displayed separately or in parts. If the segmentation level of the parameters is known only to the author of the program, no one else will be able to use the program.

1.3. Segment the program: every processing step can be carried out by a separate program with its own set of input parameters and resulting data. This will further strengthen the solutions in 1.1 and 1.2.

1.4. Segment the program: Item 1.3 can be applied, and also the program calculating the final step of the algorithm is not posted on the server, but run on the author's PC. (This also applies to the use of Inventive Principle 2. Taking out).

1.5. Segment the program: the program can be implemented in two (or more) parts, i.e. the control module directly run by the operating system, and the library (set of libraries), which contains the basic algorithm but is not functional without the control module. The control module can be stored with the user on a separate carrier (disk, USB flash drive, mobile phone, etc.) and the library, which is large and "heavy", on the shared resource. Use of the program will be available only to those who have the control module. (This also applies to the use of Inventive Principle 2. Taking out).

(Options 1.1, 1.2 and 1.3 refer to "security through obscurity" and are "bad" in terms of information security).

2. Taking out. Divide the file into unequal (different) parts.

2.1. Use item 1.4.

2.2. Use item 1.5.

2.3. To protect the program, use "key file", "key disk", or "dongle", to hold either an important piece of program code, without which the program will not function, or values of key calculation parameters, without which the results of the calculation are incorrect (this also applies to the use of Inventive Principle 9. Preliminary anti-action – spoil calculation results in advance), or decryption key code snippet of an important part of a program, or key calculation parameters (this also applies to the use of Inventive Principle 9. Preliminary anti-action – spoil program in advance).

4. Asymmetry.

4.1. Use asymmetric encryption of the input parameters with the author's private key, and (or) asymmetric encryption of the resulting data with the author's public key.

10. Preliminary action.

10.1. Use item 2.3.

22. 'Blessing in disguise'. Add a harmful factor – a special input format. This will provide the required positive effect – the program will be available only to the author. The program will only work with a specific format of input data, which the author alone knows.

22.1. Make it so that, for example, during the computation the program issues ten false messages about a critical failure, and asks the user to choose "0 - Stop / 1 - Continue." The author will select "Continue" and others - "Stop" (although this secret would be fairly easy to discover). This solution can be enhanced: the program gives an error message and ends, but saves the intermediate calculation results which are then used when the program is run again WITHOUT input parameters. After the error message, the author just restarts the program without parameters and finishes the calculation, while others will not be able to do so.

22.2. Make the program produce a nasty sound and start blinking the screen during operation. The author will start the program, turn off the sound and the monitor, while others will think there is a failure or a virus.

22.3. Include in the program code non-hazardous fragments of a virus based on popular antivirus software. The author will start the program, turning off the antivirus (or creating an exception in the antivirus for the program), while others will think there is a virus.

22.4. Make the program "slow down" all other programs in the operating system. The author will start the program at night, while others will not be able to work with it (i.e. during working hours), thinking it has an error.

24. Intermediary.

24.1. Make the program operate via a remote procedure, web-service, or database that can be accessed only by the author of the program, and allow data flow transformation to occur only with the participation of the intermediary.

24.2. Use item 1.5, but let the control module use a web-based interface on a site that only the author can access.

24.3. Compile the program so that hardware or software architecture is incompatible with the server on which it is stored, (for example, a program for Mac OS X, and the server with Windows). Then the author of the program will be able to run it on his PC (e.g., Apple), while others cannot (unless they also have an Apple PC). The solution can be strengthened: the hardware architecture can (already or still) be nonexistent or exotic (for example, "Elbrus 2000"[10]), but the author could have an emulator that will run the program from the server.

27. Cheap short-living objects.

27.1. Recompile the program every two or three days and replace the new version on the server, changing the order, size, and/or dimension of the input parameters and the resulting data. This will be much cheaper for the author to do than for others to decipher the newly formatted parameters and results each time.

27.2. Include an expiration date in the program so that it works only two or three days and stops working. After this period, recompile the program and replace it on the server. The author can use the program all the time, but not others.

27.3. Compile a stripped-down version of the program for each specific problem that solves a kind or class of problems, but does not solve other types or classes. Then erase this version, replacing it with another. The author can always recompile the program for various needs, but others cannot.

4. Conclusions

1. The logic of ARIZ [5] and adapted Inventive Principles [12, 16] can be used for solving IT problems.

2. The authors propose two new ways of solving TC for IT problems:

[10] Elbrus 2000 – From Wikipedia.

2.1. Combining subsystem functions.

2.2. Adding an additional resource.

References

1. Altshuller G. The Innovation Algorithm. TRIZ, Systematic Innovation and Technical Creativity. Technical Innovation Center, Inc. Worcester, MA, 1999. 312 p.

2. Rea K.C. Using TRIZ in Computer Science – Concurrency / The TRIZ Journal, Aug. 1999

3. Rea K.C. TRIZ and Software - 40 Principle Analogies, Part 1, Part 2 / The TRIZ Journal, Sep., Nov. 2001

4. Mann D. TRIZ for Software? / TRIZ Journal, Oct. 2004.

5. Vladimir Petrov. Logic of ARIZ – ETRIA TRIZ Futures Conference 2006. Florence, 3-5 November 2004. pp. 315-331. – The TRIZ Journal. http://www.triz-journal.com/archives/2005/11/09.pdf.

6. Umakant Mishra. The Revised 40 Principles for Software Inventions, 2006

7. Mann D.L. Systematic (Software) Innovation, IFR Press, 2007.

8. Umakant Mishra. Inventions on Auto-Configurable GUI a TRIZ Based Analysis SSRN, 2007 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1271450

9. Odintsov, I.; Rubin, M., TRIZ methods in SW development to enhance the productivity / Software Engineering Conference in Russia (CEE-SECR), 2009 5th Central and Eastern European P. 276 - 280

10. Rubin M.S. Elepoli and universal system of Standard Solution, 2010 (Russian) www.temm.ru/ru/section.php?docId=4576

11. Umakant Mishra. TRIZ Principles for Information Technology, 2010.

12. Petrov V. Adaptation of methods to resolve TC for IT. International research conference “TRIZfest-2012”. – Lappeenranta; St. Petersburg, August, 2-4, 2012: conf. proc / MATRIZ. – 154 p. P. 92.

13. Umakant Mishra. Solving Virus Problems by Anti-Virus Developers - A TRIZ Perspective, SSRN, 2012 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1978385

14. Umakant Mishra. Using Free Domains - A Case Study of Using TRIZ Resources SSRN, 2012 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1976653

15. Umakant Mishra. Improving Speed of Virus Scanning - Applying TRIZ to Improve Anti-Virus Programs, SSRN, 2012 http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1980638

16. Petrov V. Adaptation Inventive Principles for IT. International research conference “TRIZfest-2012”. – Lappeenranta; St. Petersburg, August, 2-4, 2012: conf. proc / MATRIZ. – 154 p. P. 92-99. (Russian).

17. Petrov V. The Law of Increasing Degree of Su-Field. International research conference “TRIZfest-2012”. – Lappeenranta; St. Petersburg, August, 2-4, 2012: conf. proc / MATRIZ. – 154 p. P. 50-57. (Russian).

18. Petrov V. The Law of Increasing Degree of Su-Field. The CIL Journal. 2012 http://thecontinualimprovementlab.com/wp-content/uploads/2012/10/V-Petrov-Su-Field-Paper-English-10-15-12.pdf

19. Petrov V., Voronov G. On Su-Field Analysis For Information Processing System. / International research conference “TRIZfest-2013”. – Kiev, Ukraine, August, 01-03, 2013:

conf. proc. / MATRIZ. SPb.: Publishing house of the Polytechnic University, 2013. – 300 p., p. 9-15. www.triz-summit.ru/.../Petrov%20V.%20Voronov%20G.%20A%20new

20. Umakant Mishra. Using TRIZ for Developing Anti-Virus, 2013, 461 c.

21. Vladimir Petrov. The Laws of System Evolution. Berlin: TriS Europe GmbH, 646 pages, published in Russian. INNOVATOR (06) 01/2013, ISSN 1866-4180. – 646 c.

22. Sereda S.A. The Laws of Technical Systems Evolution and Computer Software / Computer newspaper, 2002, №30 (371). p. 7. (Russian) http://consumer.stormway.ru/os_devel.htm

Author (co-author) to contact: Vladimir Petrov, vladpetr@013net.net

TRIZfest 2014

TRIZ Tools Evaluation From the Production Plant Viewpoint

Pavel Jirman, Ivan Masin[a],

[a]*Institut of creativity and innovation, Liberec, 460 01*

Abstract

With respect to the technological and technical level of current manufacturing processes, which reflects the growth of complexity and quality of existing products, it is evident that conventional tools for solving problems can not always provide sufficiently strong solution. Therefore it is necessary to continue in an effort to apply TRIZ tools also on the operational level. These tools are very well developed on a theoretical level, but their use is particularly suitable for engineers with higher technical education.

Current demands on the higher productivity and quality gives rise to the question how these tools to present to workers with lower technical education, so that they can understand them and their value is not reduced. We are dealing with the solution of this problem for several years and we will specify the problems in the article and solutions associated with the use of selected TRIZ tools to "shop-floor level.".

Keywords: TRIZ, problem solving methods, production plant, evaluation.

1. Introduction

During the Lean Manufacturing movement many methods and techniques were and still are set-up at shop-floor level. In this group tools for problem solving (5 whys, fish-bone diagram, team-based activities etc.) play important role although disadvantages of that tools are well known:

- linear logic preference
- low reproducibility
- personal experience enforcing
- macro-observations utilization etc.

The way how to eliminate fore-mentioned negative features of traditional routines and eliminate causes of "non-systematics" is clear. We should prosper from benefits reached by TRIZ-specialists. Question is why that "human oriented knowledge-based systematic methodology of inventive problem solving" did not expand enough to the all organizational levels of industrial company. We see number of obstacles that obstruct sophisticated techniques utilization at production plant:

- limited time for decision
- low capacity to make proper analysis
- aversion to „functional speech"
- non-familiarity with laws of nature

- dislike to solve problems at physical level etc.

On the other hand we can presently see several important trends that we should take into account when thinking about advanced problem solving at shop-floor level:

- booming personal electronics (e.g. smart phones, tablets, Google glass)
- free or low-price apps availability
- high ability of youth „to search“
- „crowds“ integration to democratized innovation process
- urgency to solve even common production plants problems at micro-level
- some continuous improvement teams reached „roof“ provided by traditional problem solving tools and are looking for advanced and simultaneously graspable solving techniques

The all mentioned trends indicate i.a. that time for real TRIZ-democratizing is here. That process of democratizing will be successfull on condition we will be able to choose, train and implement toolkit of user-friendly tools based on TRIZ methodology.

2. TRIZ tools for the production plant evaluation

For practical application in the production plant conditions we think complex TRIZ methodology should be converted into „toolkit“ of applicable tools and techniques both at analytical and solution level. Toolkit of selected tools and their genereal evaluation is illustrated in the Table 1. Selection of tools was based on authors experience with Lean Manufacturing implemenation and few TRIZ based training courses for production plant employees.

Table 1: Toolkit for production plants

TRIZ tool	Strengths (+)	Weaknesses (-)
9 windows	context visualisation	system view understanding
Functional Analysis	schematic	duration, functional speech
Trimming	algoritmization	functional analysis
Cause-effect chain	understanding of causes	duration
Resource analysis	simplicity	
Ideality definition	simplicity	
Trends of TS development	universality	duration,
Function Oriented Search	effectivity	software, functional speech
Technical contradictions	depth of understanding	complicated to explain
40 invention principles	universality	reproducibility
4 separation principles	universality	
Effects database	universality	software
Su-Field analysis	universality	complicated to explain

For detailed evaluation of selected TRIZ tools for production plant purposes we applied additional criterions:

- simplicity of application in the production plant conditions
- adaptibility for production plant
- visualization
- easy of presentation (to other employees)
- software requirement
- hardware requirement

Result of the detailed evaluation is included in the Table 2.

At the first look on the evaluation of the tools only simple division +, -, 0 (neutral) can be used to evaluate their suitability for further investigation and adaptation on workshop level. The following tools have been evaluated as the most adaptable:

- 9 windows
- Functional Analysis
- Cause-effect chain
- Resource analysis
- Trends of TS development
- Function oriented search
- 40 invention principles

Table 2: Detailed evaluation of TRIZ tools from the production plant viewpoint

TRIZ tool	**Criterion**						**Sum**
	Simplicity of application	Adaptibility for production plant	Visualiza-tion	Easy of presenta-tion	Software require-ment	Hardware require-ment	
9 windows	+	+	+	+	+	+	**6**
Functional Analysis	-	+	+	+	+	+	**4**
Trimming	-	+	0	+	+	+	3
Cause-effect chain	0	+	+	+	+	+	**5**
Resource analysis	+	+	+	+	+	+	**6**
Ideality definition	+	0	-	+	+	+	3
Trends of TS development	0	+	+	0	+	+	**4**
Function oriented search	0	+	+	+	+	-	**3**
Technical contradictions	-	-	+	+	+	+	2
40 invention principles	+	+	0	+	+	+	**5**
4 separation principles	-	-	0	0	+	+	0
Effects database	-	0	+	+	-	-	-1
Su-Field analysis	-	0	+	-	+	+	3

-

Data presented in Table 2 we obtained from our experience with 12 project in Czech companies. The evaluation was done subjectively in a group of several workers involved in the project. There was use simple statistics method in evaluation.

3. Application of toolkit for production plant problem solving

Application of selected tools can be presented on the example of joining parts during assembly - see Fig. 1

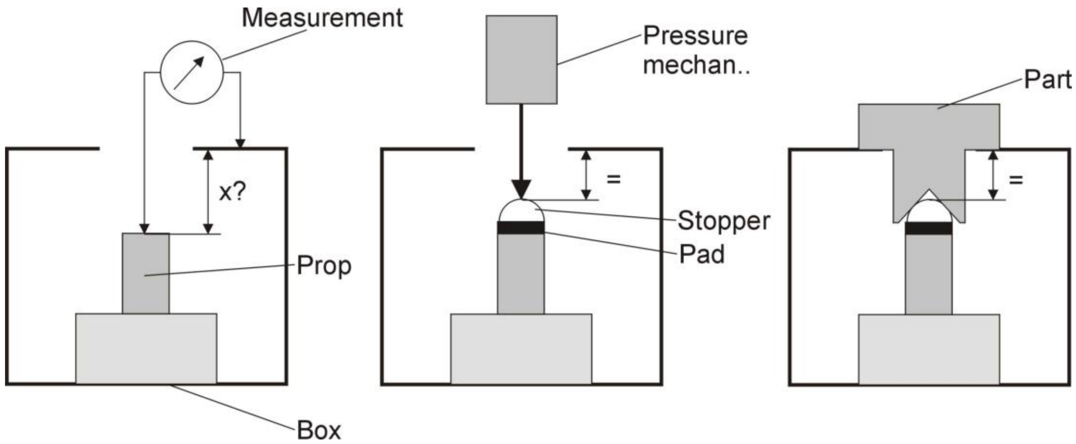


Fig. 1. - Process of assembly of parts on stop

During the assembly of parts into a box it is needed to accurately set up the stop. To do this, first, it is necessary to measure the distance of the prop from the top of the box and then manually insert the stopper with the selected height of the pad. Then the part just touches it and is thereby controlled by the stopper. It is obvious that this manual operation of adjustment of stopper reduces productivity. The cause is the inserted pad.

Selected tool for application is a simplified model of the functional analysis, that clarifies the situation- see Fig. 2

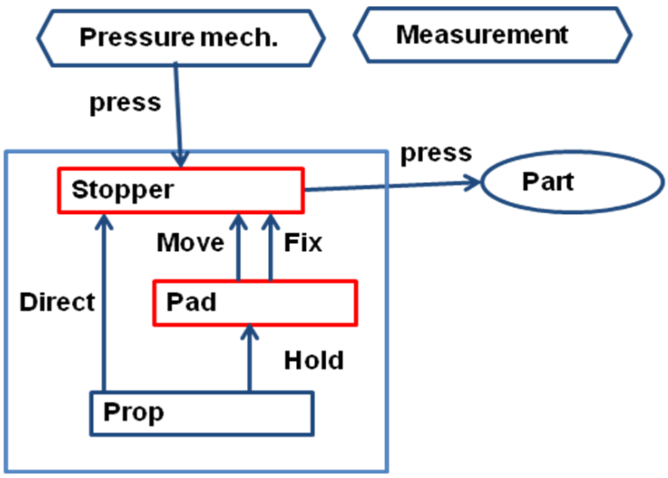


Fig. 2. Functional model of assembly parts on stop

In this model there are merged functions of a pressure mechanism and pressure of a part, which are in fact divided in time.

In this situation it is necessary to determine the place, time and source of the problem:

- Operational zone: the upper edge of the stopper
- Operational time: assembly of the box with the part
- Sources: stoper, pad, part. .

The pad is the problematic component that needs to be removed from the system.

Ideal solution: Sources in the system move the stopper to the exact position "by themselves". As the source we can select the "part". The following Fig. 3 presents the model of an ideal solution.

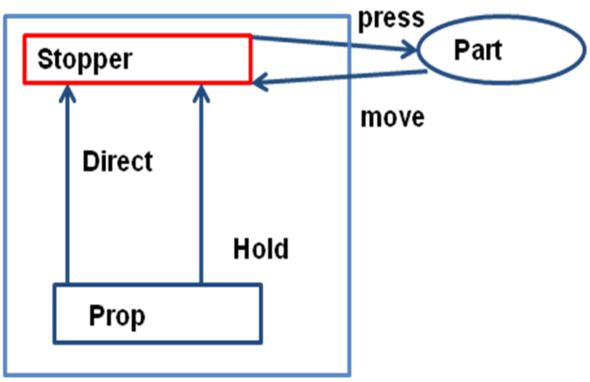


Fig. 3 - The model of an ideal solution

The description of the problem: How to change the stopper to be moveable while holding position. The stopper have to be soft at the beginning and hard at the end.

It is necessary to search for a materials which changes their properties depending on the time or temperature. Properties of substances may be generalized within the FOS and then search the change of solid state of material. There are a lot of such materials in databases which cab fulfill such a function. Final solution see Fig. 4.

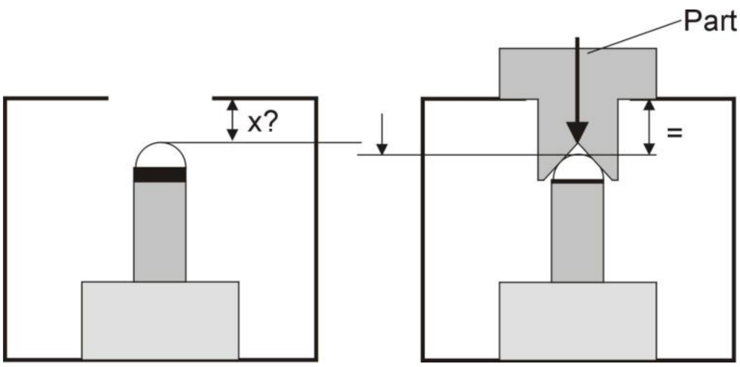


Fig. 4. Final solution of assembly parts on stop

Simple TRIZ tools from the toolkit were applied for a solution to be understandable by the worker at a workshop level. The tools included functional analysis, Operational zone, Operational time, sources and definition of the ideal solution. Ideal solution can be performed by a source which is located in the system. For searching of an appropriate material that can change the stopper the tools of FOS it can be used, which focuses on the search for generalized functions, i.e. in our case the change of solid state of material.

The presented solution has yet creative character. It managed to avoid the measurement operation and the operation of pads inserting because inserting of a higher transformable stopper can be done already in the previous automatic operation.

3. Conclusions

On the basis of the evaluation of selected TRIZ tools several tools for work at a shop-floor level can recommended. The selected tools might be preferred:

- 9 windows
- Functional Analysis
- Cause-effect chain
- Resource analysis
- Function oriented search
- 40 invention principles

These tools will be necessary to be modified for their use in the graphical form. Other tools may be to discussed according to the complexity of the problems appearing in the solution.

The evaluation of the TRIZ tools and their application mentioned above show possibility to use selected tools at shop-floor level. It is the start for real TRIZ-democratizing. That process of democratizing will be successfull under the condition that selected TRIZ tools demonstrate their adaptability to different conditions at shop-floor level and workers will accept them.

References

1. Rantanen K.,Domb E. Simplified TRIZ, CRC Press, LLC, 2002, London, ISBN 1-57444-323-2

1. Mašín I, Jirman P. Metody systematické kreativity (Methods of systematic creativity). Technická univerzita v Liberci. Liberec 2012. ISBN 978-80-7372-853-3

2. Kyeong W.L. Quick TRIZ process and the related TRIZ activities in Korea. Japan TRIZ Symposium 2010, Kanagawa, 2010

3. Masin I, Jirman P. Systematic creativity techniques for continuous process improvement. In: Proceedings of the International Conference TRIZ Future 2011, Dublin, p. 321 – 326.

4. Masin I, Jirman P. Production problems solving based on negative effect and non-desirable component identification. In:. Proceedings of the International Conference TRIZ Future 2012, Lisbon, p. 523 – 528.

Author (co-author) to contact: Pavel Jirman, jirman@glass.cz

TRIZfest 2014

Value Conflict Mapping Plus (VCM+): Adding Business Dimensions

Andrei Kuryan[1], Valeri Souchkov[2]

[1] *IT Mine Training Center, Melezha 1, 1121 Minsk, Belarus*

[2] *ICG Training & Consulting, Enschede, 7511KH, The Netherlands*

Abstract

The paper presents a framework for expanding the Value Conflict Mapping approach originally developed for collecting information on contradictions which block further product evolution of a technical system (product) with respect to market demands and requirements. The expansion consists in adding contradictions which also consider both value proposition created for a technical system and a business organization which creates and maintains the product lifecycle. The goal of a new approach is to discover contradictions outside the design and technologies the product is based upon. Such contradictions relate to business organization and market methods used by the business system. Discovery of such contradictions helps to broaden the range of opportunities to solve contradictions and further evolve value proposition to gain competitive advantage. The paper is illustrated by an example.

Keywords: Value Conflict Mapping, contradictions, innovation roadmapping

1. Introduction

Classical TRIZ was developed for engineering and technology. In general, an engineer's task is to solve problems related to changing an existing technical system (or, for example, an information system) or developing a new technical system to meet specific market demands and requirements. TRIZ is supposed to provide help to an engineer in situations when certain technical demands contradict each other.

Ideally, an engineer should obtain product demands and requirements specified by a business leader (entrepreneur) unless the engineer is an entrepreneur himself. The business leader collects demands from stakeholders and then the demands are translated to product specifications. Second, he evaluates risks and makes decisions on production and distribution of a new or improved product. However vision of the business leader must not be limited to a product or product-related services only. The business leader has to deal with a broad scope of demands to correctly identify value proposition for specific market segments as well strategic constraints imposed by his business organization.

Any business is launched to meet expectations of its founders and owners. These expectations might vary but the most common expectation is obtaining profit. Profit can be made by selling a product which can be positioned for different markets. In order to develop and distribute the product the business owners establish a business organization.

Fig. 1. A model of a business system

As a result, all three components: a product, a business organization and a market are the components of a business system. As follows from this model of a business system (Figure 1), value proposition created by a company is not limited to the product but involves the business organization which develops and distributes the product and the ways the market is accessed by the company.

For example, a company which offers international logistics services creates value proposition which is not limited to transportation services only. To simplify financial operations between all agencies involved, the company establishes branches in different countries which use local currencies to operate with local customers and hire employees who are native speakers. This way the business operations become more complicated but provides additional benefits for their international customers.

2. Improvement of a Business System through Product

It is well known that a business system, especially one which develops technology and engineering related products, can be improved through improving the products. One of the methods which is widely used to identify what improvements have to be made is Quality Function Deployment (QFD) [2].

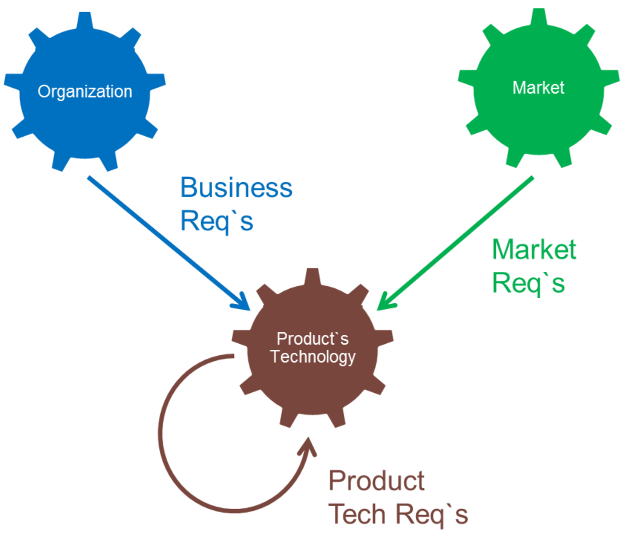


Fig. 2. Gathering information about demands and requirements

Modern versions of QFD assume that one can explore opportunities for future product improvement on the basis of collecting as many requirements as possible from each party (stakeholder) interested in such the improvement (Figure 2). The following voices must hence be accounted:

- Voice of the market
- Voice of the business
- Voice of the product (or, technology which is used in the product)

During the next project phases these requirements are mapped to decisions specifying how the product should be changed to meet these requirements.

The QFD method however has the following limitations:

1) QFD does not guarantee completeness of the list of requirements of all stakeholders.
2) QFD does not contain tools for discovery and resolution of contradictions emerging between different requirements.

3. Value Conflict Mapping

The abovementioned disadvantages of QFD are removed in Value Conflict Mapping (VCM) [3]. VCM is an analytical tool developed for identification and ranking of so-called "blocking contradictions" that delay further evolution of a system and is positioned to support the analytical phases of an innovation roadmapping process. During analysis with VCM, the product demands and requirements are mapped to the desired relative values of various product attributes, for example, to physical parameters. Further, the values are inverted to check if a specific value of an attribute causes a contradiction and to discover new requirements and demands which were neglected after collecting the original set of demands and requirements. For example, if one of the demands for a bicycle is "easier to ride" then it is mapped to the relative value "large" of the attribute "diameter" of the bicycle's wheel. It is obvious that the wheel should be large to make riding easier. At the same time, the inversion of the relative value "large" to "small" brings a new set of demands and requirements which can be only achieved with a wheel of small diameter (Figure 3).

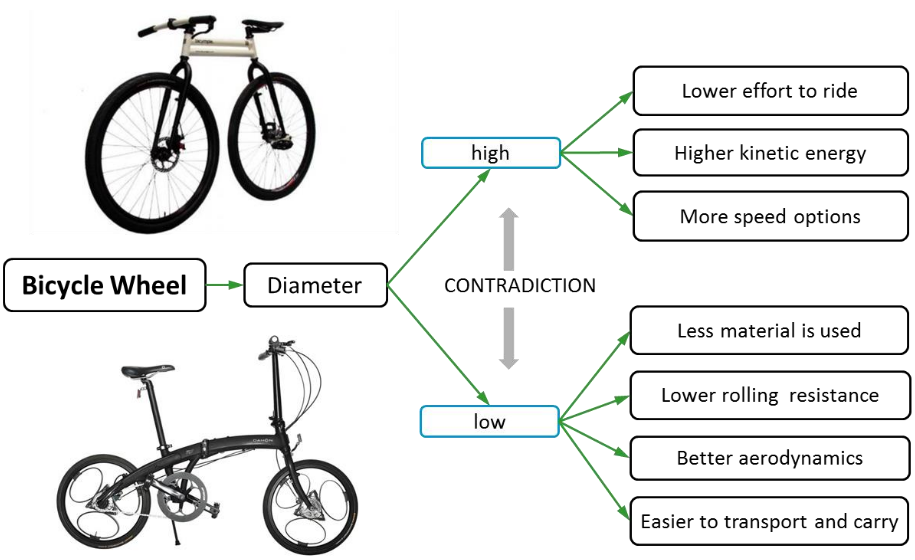


Fig. 3. Example of value inversion in VCM

Inversion of relative values of an attribute presenting a system makes it possible to extract a so-called "pseudo-contradiction": a certain specific parameter must have relative value "+A" and at the same time must have relative value "-A". Such a pseudo-contradiction becomes an actual contradiction if one discovers that the value "-A" meets a certain requirement of a stakeholder. For example, small diameter of the bicycle's wheel meets the requirement "the bicycle is easier to transport and carry". A fragment of a typical VCM output table in shown in Table 1.

Table 1. A fragment of a typical VCM table

#	MARKET DEMAND	SUBSYSTEM	ATTRIBUTE	VALUE
C1	Smooth running	Tire	Elasticity	High
C1		Tire	Elasticity	High
C1	Long tire lifetime	Tire	Elasticity	Low
C1	No need to replace tire	Tire	Elasticity	Low
C2	No sail effect	Wheel	Hollowness	High
C2	Higher stiffness	Wheel	Hollowness	Low
C2		Wheel	Hollowness	Low
C3	Easy to carry	Wheel	Diameter	Small
C3	Easy to cycle	Wheel	Diameter	Large
C3		Wheel	Diameter	Large
C3	Easy maintenance	Wheel	Diameter	Large
...	...	...	...	...
C54	Better visibility in the dark	Lamp	Light Intensity	High
C54		Lamp	Light intensity	High
C54	Less blinding	Lamp	Light intensity	Low
C54	Less energy spent	Lamp	Light intensity	Low

As seen, VCM helps with discovering physical contradictions which are currently present in a system (or its subsystems). Physical contradictions are formulated with respect to a certain subsystem that must have two contradicting values of its physical attribute: either physical parameter or physical state. Figure 4 shows how "pseudo-contradictions" are identified in VCM.

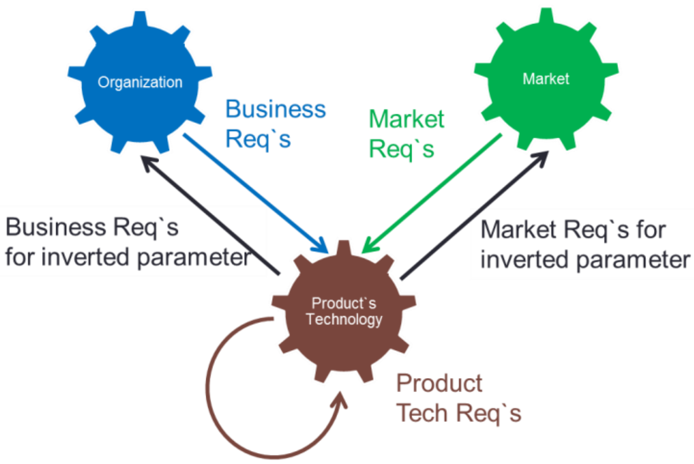


Fig. 4. Indentifying pseudo-contradictions in VCM+

A disadvantage of VCM that such contradictions can only be solved by physical changes of a technical system. Such limitation does not allow one considering other ways of resolving contradictions, for example by changing a business model or updating the market methods.

At the same time, the most effective and efficient innovative solution (which is the closest to the ideal one) might reside outside the technical system. In such cases, solutions might demand considerably less resources to be implemented while the desired goals are fully achieved.

For example, in the beginning of the 2000s, a mobile phone market started to face serious obstacle: sales of the mobile phones dropped due to very high prices of the phones which did not meet expectations of consumers. An engineering approach to solving the problem would be to cut production costs of the phone as much as possible by engineering redesign of the phone and its subsystems. However this approach did not seem to be feasible due to high costs of components and materials which were purchased from suppliers by phone manufacturers. A solution was found by changing a business model: a contractual system was proposed in which the full price of a phone was broken to relatively small monthly payments during one or two years together with additional benefits. The solution significantly reduced the price tags of the phones in shops thus making purchase of the mobile phones psychologically attractive for consumers.

4. VCM+: additional dimensions

This paper proposes further development of the VCM method: VCM Plus (VCM+). VCM+ eliminates the disadvantage of VCM related to limiting information gathered during analysis. VCM+ expands a scope of analysis by considering the entire value proposition proposed by a business system in addition to the product specifications as well as a business system around the value proposition.

Contradictions emerging in the value proposition can be solved not only by changing the product's technology but in the organizational and market methods of the business system.

5. Types of contradictions in a business system

Within the business system, that requirements and demands of different groups of stakeholders can lead towards emergence of contradictions of different types. Figure 5 shows these types of contradictions while Table 2 provides their description and examples.

Table 2. Types of contradictions in VCM+

Contraduction	Примеры
Product\`s technology vs Product\`s technology	A car engine must be powerful to provide high speed of the car and at the same time it does not have to be powerful to limit fuel consumption.
Product\`s technology vs Market	A body of a high-end smartphone must have openings to provide effective cooling of microprocessor and at the same time must be sealed to be waterproof.
Product\`s technology vs Organization	An automotive company produces a series of budget cars. On one hand, the market demands cars of different colors while on the other hand making the cars of different colors increases production costs that contributes to increasing the consumer price of the car.

Market vs Market	Microsoft Project software package provides many functions and features for an advanced user but at the same time they complicate work of a beginner.
Market vs Organization	Consumers prefer to have customized service while paying low prices while customization of services requires considerable extra spending by the company.
Organization vs Organization	To increase sales volume a company must hire additional sales force but it leads to increasing sales costs.

It is clear that the first three types of contradictions include technical product and technology it is based upon. These types of contradictions are the subject of consideration by classical TRIZ. The latter three types of contradictions are directly related to neither the technical product nor its technology. Until recently these contradictions were not supported by TRIZ while a business system faces such contradictions rather often.

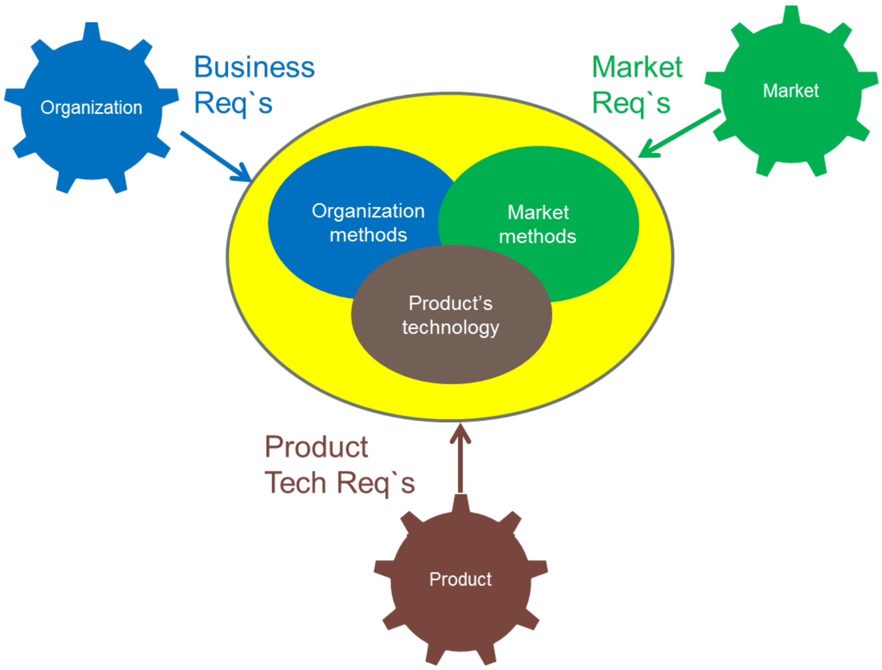


Fig. 5. Expanded framework in VCM+

As a result a technical product can be seen as a part of a more general value proposition while an engineer usually only considers demands and requirements within the context of the product and its technology. Quite often an engineer might not be even aware of requirements outside his product and its technology.

For example, a company sells real-time truck monitoring services. One of the services includes installation of special devices on customer's trucks to enable online tracking and monitoring of fuel consumption. However after a while after installation many devices started to fail. It was found that the devices were intentionally disabled by truck drivers so they could illegally sell fuel while during the ride. The truck drivers were thus not interested in the fact that their management would monitor in real time information about exact amount of fuel remaining. Under such conditions, the drivers would have trouble with matching the norms of fuel consumption established. The existing possibility of breaking the monitoring device decreased customer satisfaction and led to reduced sales of the monitoring devices.

6. Transformation of a contradiction

From the engineer's point of view, a problem mentioned in the example above can be solved by improving the technology of the monitoring device. In Table 1 such contradiction belongs to the category "Product`s technology vs Market". Classical TRIZ would propose to think towards creating an ideal monitoring device which can never be broken.

From the point of view of the whole business system, there are more opportunities to solve the problem. The monitoring device produces data which are useful for managers of the transport company but not wanted by the truck drivers. In other words, the contradiction emerges between two groups of customers: the managers of the company and the truck drivers. Such contradiction belongs to the category "Market vs. Market" in Table 2.

Such contradiction can be solved by changing the market methods rather than changing the product. The market demands have to be mapped to the entire value proposition rather than to the product only. For example, a service proposed by the company producing monitoring devices should provide managers with reliable non-stop monitoring of fuel consumption and at the same time do not complicate matching norms by the truck drivers.

An ideal solution would be to get truck drivers interested in matching norms. A solution proposed was to provide the managers and the drivers with data about costs savings made during the ride instead of physical volume of fuel spent and compensate these savings by providing the truck driver with a bonus. In this situation, the driver becomes interested in the continuous and robust work of the monitoring device.

7. Conclusions

Originally, VCM was based on the approach to map market and customer demands and requirements on the product and its technology thus identify contradictions related to the product and its technology only.

We see evolution of VCM by expanding it with a possibility to map the demands and requirements to both business organization and market methods in addition to a product and its technology thus covering the entire business system. Therefore the list of contradictions in VCM+ includes both contradictions related to the product and its technology as well as contradictions related to the other parts of the business system.

An additional benefit of VCM+ is a possibility to map the demands and requirements related to the product and its technology to the business organization and market methods. Such the possibility considerably expands the area of application of VCM+. As a result, a wider range of opportunities for solving a particular problem will be created. For example, VCM+ can be used at Step 6.3 of ARIZ-85C [5] to replace a problem.

Both VCM and VCM+ produce lists of contradictions related to various aspects of a selected product as outputs. VCM+ therefore creates a longer list of contradictions resolving which would help to improve not the product only but the entire value proposition by improving business organization and market methods.

It is obvious that to apply results obtained with VCM+ will require development and improvement of the existing TRIZ methods and tools to support problem solving in the areas of business, management, and marketing.

References

1. Shnaider A., Kazman Ya. & Toptshivili G. A Science to Win in Investments, Management and Marketing. Moscow, ACT, 2003. ISBN: 5-17-015166-7. (in Russian).

2. Yoji Akao. Quality Function Deployment: Integrating Customer Requirements into Product Design. Productivity Press, 1990. ISBN 10: 915299410
3. Souchkov V. "Value-Conflict Mapping to Structure Innovation Strategy", in the Proceedings of Int. Conference TRIZ Future 2008, University of Twente, Enschede, The Netherlands, 2008, p. 235-242. http://www.xtriz.com/publications/Souchkov_Value_Conflict_Mapping.pdf Last seen: June 28, 2014
4. Kuryan A. Towards Refining a Definition of Contradiction. http://triz.by/articles/refinement-of-the-notion-of-contradiction-in-triz.html. Last seen: June 26, 2014.
5. Altshuller G., Algorithm for Solving Inventive Problems ARIZ-85B, Sverdlovsk, 1985 (In Russian)

Author (co-author) to contact: Andrey Kuryan, andrew.kuryan@gmail.com

Author's Index

TRIZfest-2014 International Conference Proceedings

September 4-6, Prague, Czech Republic

Organized by the International TRIZ Association – MATRIZ
Hosted by the Czech Union of Inventors and Rationalizers

Editors: Valeri Souchkov, Tuomo Kässi

The collection of papers «Proceedings of TRIZfest 2014 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/eduation.

All presented papers are peer-reviewed.

ISSN: 2374-2275
ISBN: 978-0-692-27134-6

Published by the International TRIZ Association - MATRIZ
8946 Wesley Place, Knoxville, TN 37922 USA
www.matriz.org