01/2017 (03)

Journal of the European TRIZ Association

INNOVATOR

Special Issue:
Selected papers presented at the 16th International TRIZ Future Conference, October 24-27, 2016, Wroclaw, Poland

Journal of the European TRIZ Association – ETRIA e.V.
INNOVATOR, ISSN 1866-4180, 01/2017 (03)

All papers accepted for publication in this Special Issue were submitted to the Conference Organizing Committee as full papers and were double peer reviewed. Authors were given the opportunity to amend their paper in light of these reviews before the decision to accept and publish the paper.

The Journal of the European TRIZ Association (ETRIA) has been set up to accomplish the following tasks:

- Promotion of research and development on organization of innovation knowledge in general and particular fields by integrating conceptual approaches to classification developed by artificial intelligence and knowledge management communities,
- International observation, analysis, evaluation and reporting of progress in these directions,
- Promotion on an international level of the exchange of information and experience in the Theory of Inventive Problem Solving TRIZ of scientists and practitioners, of universities and other educational organizations,
- Development of TRIZ through contributions from dedicated experts and specialists in particular areas of expertise.

Imprint:
INNOVATOR
Journal of the European TRIZ Association
ISSN 1866-4180
Publisher: ETRIA e.V.
Editors: Gaetano Cascini, Pavel Livotov
Guest editors: Tomasz Arciszewski, Sebastian Koziołek
ETRIA e.V. - European TRIZ Association
Basler Str. 115
D-79115 Freiburg - Germany
Internet: www.etria.eu
E-Mail: info@etria.eu

01-2017 (03)
INNOVATOR ● ISSN 1866-4180 ● Journal of the European TRIZ Association - ETRIA e.V.

Content

Sustainable European Collaboration in the Field of Knowledge-Based Innovation and Inventive Problem Solving with TRIZ

Pavel Livotov

President of the European TRIZ Association ETRIA e.V., Basler Str. 115, 79115 Freiburg, Germany
Offenburg University of Applied Sciences, Badstr. 24, 77652 Offenburg, Germany

In the modern continuously innovating economy, the value of new intellectual property is growing faster relative to other assets. Therefore, the technological leadership through innovative strength, the ability to rapidly find breakthrough solution ideas, and to successfully implement innovation concepts become crucial factors for competitive capability of organizations and intellectual potential of society.

The Theory of Inventive Problem Solving (TRIZ) is regarded today as one of the most comprehensive, systematically organized invention knowledge and creative thinking methodologies [1]. TRIZ delivers scientifically founded and structured approach to forecasting evolution of technological systems, includes numerous tools and methods for product and process innovation, and enables marked increase of creative and inventive productivity over traditional innovation supporting methods. The classical TRIZ, developed by Genrich S. Altshuller (15.10.26-24.09.98) and his co-workers [2] has been significantly further developed and supplemented during two recent decades.

The European TRIZ Association (ETRIA), founded as a non-profit organization, on 15.10.2000, acts as a connecting link between scientific institutions, universities and other educational organizations, industrial companies and individuals concerned with conceptual and practical questions relating to organization of innovation process, invention methods, and innovation knowledge [3]. Since its foundation the ETRIA has been successfully organizing annually international TRIZ Future Conferences (TFC) in co-operation with the European Universities, research institutions and industrial partners with the following objectives:

- Promotion of theoretical and applied research on structured innovation models, methodologies, and tools with a focus on inventive design and creative problem solving;
- Promotion of exchanges among academic and industrial researchers with complementary background and research interests in the field of artificial intelligence, computer science, knowledge management, inventive creativity, design approaches, and IP management;

- International observation, analysis, evaluation and reporting of scientific progress in the fields mentioned above;
- Promotion on an international level of the exchange of information, experience and education initiatives of universities and other educational organizations in the fields of TRIZ and innovation design methods;
- Development of TRIZ through contributions from dedicated experts and specialists in their areas of expertise.

The flagship of ETRIA activities is the annual international TRIZ Future Conference (TFC). Its tradition dates back to the first ETRIA conference at the University of Bath, United Kingdom in 2001, followed by other conferences, supported or hosted by the academic institutions: ENSAIS Ecole Nationale Superieure des Arts et Industries, Strasbourg (France, 2002), RWTH University and Fraunhofer Institute of Production Technology in Aachen (Germany, 2003), University of Florence (Italy, 2004), University of Leoben (Graz, Austria, 2005), University of Leuven (Kortrijk, Belgium, 2006), IHK Chamber of Commerce and Industry (Frankfurt am Main, Germany, 2007), University of Twente (Enschede, The Netherlands, 2008), University of Timisoara (Romania, 2009), University of Bergamo (Italy, 2010), Institute of Technology Tallaght (Dublin, Ireland, 2011), New University of Lisbon (Portugal, 2012), Ecole Nationale d'Arts et Métiers, Paris (France, 2013), EPFL École Polytechnique Fédérale de Lausanne (Lausanne / CERN, Switzerland, 2014), Technical University Berlin and others (Berlin, Germany, 2015), Wrocław University of Science and Technology (Wroclaw, Poland, 2016), including the next TFC2017 conference at the Lappeenranta University of Technology LUT, Finland.

In the meantime, more than TFC 1000 papers or presentation of scientists, educators, and practitioners from all over the world are available at the official ETRIA website [3]. Numerous research projects were supported or funded by the European Commission [4]. In 2010 the ETRIA Executive Board started the initiative aiming higher visibility of recent scientific findings in TRIZ and knowledge based invention in the scientific communities [5]. Thanks to the partnership with the International Academy for Production Engineering CIRP and the publisher Elsevier, the 222 selected scientific papers of the TRIZ Future Conferences 2006-2015 have been published in three Elsevier Procedia volumes, available at the ScienceDirect.com in open access [1, 5, 6]. Additionally, the Journal of the European TRIZ Association INNOVATOR has been founded in 2014 for the further dissemination of the conferences papers and other contributions. The current ETRIA Journal volume 03 presents a part of papers of the 16th TFC “Systematic Innovation and Creativity” held in Wroclaw, Poland on October 24-27, 2016.

Since its establishment in 2001 the ETRIA community has evolved to a strong international scientific group extending beyond the borders of the EU with the members and organizations

from all continents. The ongoing collaboration within the community has significantly contributed to a further development of TRIZ and led to creation of new areas of expertise such as:

- Automated technologies to analyze complex situations and to identify contradictions in technical systems, products and processes;
- Techniques for fast and comprehensive solving inventive and innovative problems;
- Structured formulation of innovation strategies for front-end innovation;
- Systematic identification of market needs, technical requirements and corresponding solutions,
- Semantic data processing technologies to retrieve, categorize, and use innovation knowledge assets, including patent mining;
- Integration of TRIZ and new TRIZ-based tools in all phases of innovation and new product development processes;
- Advanced methods for risk assessment and anticipatory identification of secondary problems in innovation concepts;
- New creativity techniques to overcome psychological inertia,
- Modern educational concepts, tools and recommendations for schools, universities, and organizations; development of methodological [7] and educational standards in TRIZ
- Advanced application of TRIZ in the specific domains such as process engineering, software engineering and IT, environmental engineering, business and management.

References

1. Cavallucci, D., Cascini, G., Duflou, J. et al (2015) TRIZ and Knowledge-Based Innovation in Science and Industry, Procedia Eng. 131 (2015) 1–2. doi:10.1016/j.proeng. 2015.12.341.
2. Altshuller G.S. (1984) Creativity as an Exact Science. The Theory of the Solution of Inventive Problems. Gordon & Breach Science Publishers, 1984, ISSN 0275-5807.
3. The European TRIZ Association ETRIA e.V. – Official website: www.etria.eu/portal
4. European Commission. Database of EU-funded research and innovation projects. Official website: https://ec.europa.eu/info/research-and-innovation/projects/project-databases_en
5. Cavallucci, D., Vaneker, T., Cascini G. et al (2011) Towards more visible scientific findings in TRIZ communities through ETRIA. In Proceedings of the ETRIA World TRIZ Future Conference. Procedia Engineering, Volume 9, Pages 1-754 (2011), p 1-2. https://doi.org/10.1016/j.proeng.2011.04.001
6. Belski, I. (2016) Structured Innovation with TRIZ in Science and Industry: Creating Value for Customers and Society. Procedia CIRP. Volume 39, Pages 1-230 (2016).
7. VDI Standard 4521 (2016). Inventive problem Solving with TRIZ. Fundamentals, terms and definitions. Association of German Engineers VDI, Berlin, Germany.

A Brief Theory of Inventive Problem Solving (BTIPS) – an Approach to the Engineering Problem Solving in Teaching, Learning and Practice

Zbigniew M. Bzymek

University of Connecticut, U-3139 ME, 191 Auditorium Road, Storrs, CT 06269, USA

Tel.:0-01-860-486-2275; fax: +0-01-860-486-5088. *E-mail address:* zbigniew.bzymek@uconn.edu

Abstract

The problem solving method described in this paper is called a Brief Theory of Inventive Problem Solving (BTIPS) and was developed on the basis of TRIZ and TIPS with the influence of the Axiomatic Design method. The general algorithm and procedures are slightly different than in TRIZ and TIPS, and some new principles, improving features, effects and system components like virtual elements are introduced. This paper is also presenting materials gathered through experience gained during the undergraduate and graduate teaching and industrial consulting. The application of the method starts with the definition of the problem that has to be properly separated from the environment. The problem solving approach includes the right sequence of steps, definition of contradictions, choice of solution modules, algorithms, definition of designed system and subsystems and choice of elements and objects. The derivation of End Solution is described and the necessary tests proving that the End Solution is the Ideal Solution are given. The recommendations for the proper path to the End Solution are given and the procedures are discussed. The tests of Ideal Solution's effectiveness and economy are also given. Some students' and engineers' opinions are included and recommendations for further education and engineering practice in problem solving are derived. This paper is devoted to the problem solving theory however some characteristics of application software are also discussed.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Engineering Conceptual Design (ECD), Problem Solving (PS), PS Procedures and Algorithm (PSPA), Design Principles (DP), Technological Effects (TE), Structure of Designed System (SDS), End Solution (ES), Trimming (T), Ideal Solution (IS).

1. Introduction

Human actions are based on the thinking processes. These processes (Figure 1) are composed of two categories: General Thinking and Problem Solving Thinking [1, 2, and 17]. Problem Solving methods consist of two groups: solving problems whose general solutions are known and solving problems whose solutions have to be discovered. The first group covers the objects that differ from known examples by size, configuration and magnitude of solution space. The second group concerns new problems whose solutions are not known and have to be derived according to innovative and inventive processes. In the second group two ways of solution approach can be distinguished – psychological and algorithmic. Psychological approach is based on the fundamental works of Sigmund Freud [3] and Brain Storming processes introduced by Alexander Fainckey Osborn [4]. Algorithmic approach, that contains processes based on the works of Henry Altshuller [5], seems to be the most promising. Out of Altshuller's method several approaches were developed and used: TRIZ (Teoria Reshenii Isobrazitielskich Zadatsh) [5, 18], Ideation [6], TIPS (Theory of Inventive Problem Solving) [7, 10] and BTIPS (Brief Theory of Inventive Problem Solving) [8, 9]. In BTIPS that originated from TIPS and IM™ several procedures, approaches and nomenclature terms are accepted from [7] and [10]. Problem solving tasks are usually approached by iterations which, if properly done, may lead to the End Solution (ES). The ES, if performs desired functions and passes the final tests, could, at the end of the process, be discovered to be an Ideal Solution.

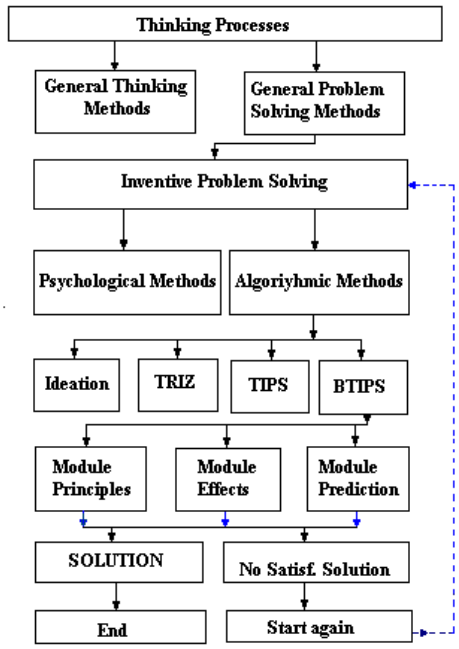


Figure 1 Thinking structure [8, 17] showing use of algorithmic problem solving methods developed from TRIZ.

The thinking process [17] has generally many functions. One of them - inventive problem solving - is in the scope of interest of this paper. The inventive problem solving process is kind of problem solving that is much more effective when the algorithmic methods are used. TIPS and BTIPS are much more effective if supported by problem solving software. There is still no ideal software suitable for a satisfactory automation of the engineering conceptual design. However there are some program packages that could be helpful and would positively influence the quality of the designed products, especially in cases of contradicting constraints. In this paper some results based on the use of Invention Machine (IM ™) software products are presented. Such packages as original Invention Machine V.2 for Windows [10] and TechOptimizer [11] were used wildly, giving good results in teaching, research and practical applications. Some positive results with use of HIS Goldfire [12] were also achieved.

2. Notations

Abbreviations and acronyms used in this paper are usually explained in the text of the appropriate section after they are introduced for the first time. For convenience of the reader however, they are listed in the box below.

Nomenclature

ECD	Engineering Conceptual Design
PS	Problem Solving
PSPA	Problem Solving Procedure and Algorithm
DP	Design Principle
TE	Technological Effects
SDS	Structure of Design System
ES	End Solution
IS	Ideal Solution
T	Trimming
PrS	Preliminary Solution
WF	Worsening Feature
IF	Improving Feature
PrSt	Problem Statement
DS	Designed System

3. A need for an effective engineering problem solving method

Our world is constantly changing creating needs for new products that will serve the society better and more effectively. All kinds of new machines, new methods and new software systems are introduced. This has significant reflection on engineering practice and education, and creates new directions and interpretation of the profession. In order to respond to this impact we have to reposition the accents and create new trends in fabrication of goods and environmental structures, new methods and new software. This also demands new development directions and new interpretations of the needs as well as rapid actions in manufacturing of modern artifacts. Engineering Conceptual Design, especially PS, which is the main goal of engineering, consists of several stages. The methods and computer software for support of the most of Detail Design and Manufacturing and Production stages were developed in 20th century. The great challenge of 21 century is

to develop tools supporting the two most uncontrollable phases of design — the problem solving and concept generation process. These processes depend on the talent and experience of designers and manufacturers, and in conventional approach are being solved in the most traditional way. There are still no sufficient tools for optimal support of those two qualities. Such tools – methods and software - could be most helpful in engineering conceptual design and would greatly influence the quality of the product especially in cases of contradicting constrains. At first, such cases appear impossible to be solved but after careful studies and appropriate efforts they may became solvable. Solving them might decide about the success of the product, giving enterprises that are using them significant advantage over the competition and let them to satisfy demands of the society. The opinion, that TRIZ and TIPS have chance to become a revolutionary conceptual design tool, is widely spread. During teaching experience it was discovered that both methods are slightly too lengthy for fast effective learning. It was also discovered that from the point of view of the modern technology they are not complete. Taking under consideration these opinions the alterations were proposed. After applying the alterations, changes, abbreviations and additions the modified method was developed and called BTIPS - Brief Theory of Inventive Problem Solving. The modified abbreviated method proved to be handy in teaching and at the same time powerful enough to be use in engineering practice. The comparison of chosen algorithmic methods and some characteristics of BTIPS are presented in Appendix (Tables A1 – A5).

4. BTIPS as a tool in engineering problem solving education

To improve the problem solving teaching and learning process as well as the design knowledge and practice, one has to address design education first. For this reason a procedure to use BTIPS in the educational applications was created (Table 1).

Table 1. Preparations for using BTIPS in PS learning

Action	Comments
Identify the Problem	
State the Problem clearly	
Isolate the Problem	From environment
Discover contradiction(s)	

After the problem was identify and properly isolated the solution attempt can be made. To do this the appropriate modules of BTIPS should be chosen. It is advisable to start the PS process by applying the module Effects that has potential to give immediately the desired solution (Table 2).

Table 2. The sequence of operations used in PS procedure

Action	Comments
State the Problem clearly	
Isolate properly the Problem	
Formulate contradiction(s)	
Use Effects first	Look for satisfactory ES
If ES found, go to Table 4	

If application of Effects did not bring any satisfactory ES, module Principles should be used (Table 3).

Table 3. Application of Principles

Action	Comments
Choose the Preliminary Solution (PrS)	It should solve the immediate (main) problem even if creating another, hopefully less serious
Define Improving Feature (IF)	
Define Worsening Feature (WF)	
Choose Principle(s) the could solve WF	
Is the contradiction solved?	If not, go to another Design Principle and try again
If contradiction is solved define the ES	Test the ES using Table 4

If you have found the End Solution (ES), check, using Table 4, whether or not it is in fact the Ideal Solution (IS), if not, proceed to the next BTIPS module i.e. Prediction (Table 5).

Table 4. The tests of ES to check whether or not it is the IS

Action	Comments
Trim the ES	If there is nothing to trim it may be the IS
Is information to describe ES minimum?	If yes, it may be the IS
Are functions*) in ES separated?	If yes, it may be the IS
Is ES using the minimum energy?	If yes, it may be the IS
Is the maintenance of ES minimum?	If yes, it may be the IS

*) see [13]

If all the ES tests in Table 4 are satisfied**) it is probably the IS, if not, one should continue the search using Prediction.
**) There are still economy and possibility tests to perform.

Table 5. Preparations for IS search using Prediction

Action	Comments
Describe the Designed System	Use the PS
Indicate the hierarchy - describe the Super-System	
Describe the Sub-Systems	
Describe the Elements	
Describe the Items	
Introduce the added physical components	If needed
Introduce the added virtual components	If needed
Propose what components can be the joined	
Propose what component can be eliminated	Decide where to delegate its function

---

After necessary preparations use the Prediction scheme developed according to Table 5 to find IS (Table 6).

Table 6. Operations on the Designed System (DS)

Operations	Comments
Describe the relation between the components	Positive, negative, neutral
Change the neutral relations into positive	If possible
Eliminate the negative relations	Or change them into neutral
If needed add new physical components	Indicate how they would improve the DS, what part
If needed add new virtual components	Indicate how they would improve the DS, what part

---

If by changing the Designed System (DS) you would arrive into the End Solution (ES) that would satisfy the desired function(s), check, using Table 4, whether or not it is the IS. If not, negotiate changing the Problem Statement (PS) and try to use BTIPS modules (Table 1) again with the new PS.

5. Problem solving examples

Below are three examples that show the use of three modules of BTIPS. Example 1 shows the use of Effects. Problem statement in this example requires elimination of sand from a jet engine that is used in the desert. According to Table 1 it is stated that the problem designed system is isolated in the space of jet engine. From the knowledge of physics one knows that if the mass is moving along the curve it is subjected to the centrifugal force (Figure 2) so effect of physics is used to solve technological problem [2].

Example 2 shows the use of Principles. It is much known from literature [10, 11] and it is illustrating very well the power of Principles. It concerns the fire preventing in steel quenching in oil. The Improving Feature is the use of a lid to cut the oxygen supply. In such a case the contradiction is: “there is a lid and there is no lid”. The Worsening Feature is “difficulty of crane access to the quenching container”. The principle of phase transition is used to solve the problem. According to that principle the lid made out of gas, that is heavier than air, stays on the surface of the oil and is preventing the access of oxygen to the oil but leaving the free access to the container for the crane. So Ideal Solution is the lid made of gas (Figure 3).

Example 3 shows the application of Prediction to improve braking on the highway during the winter time in a snowy climate. The system is composed out of the tire and pavement. Known solution to place sand between the tire and the pavement. It is not the IS however. The proposed Ideal Solution is a wire (Figure 4) heated pavement. In the view of the solar energy supply this could become a IS operating with almost no maintenance.

Example 1. Sand removal from a jet engine

Solution Method – Using centrifugal force – Effect of Substance Removal [10, 11].

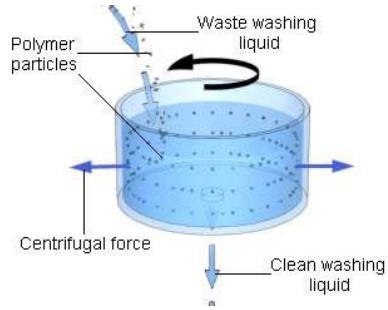


Figure 2. Centrifugal force effect [2]

The centrifugal force due to the rotation of blades and vanes pushes the sand particles toward the walls (Figure 2). A chamber should be set up inside the wall that is collecting sand particles. The bypass air flow will take the particles out of the engine.

Example 2. Quenching metal in oil [9, 10, 11]
To prevent oil from burning, there should be a lid to separate the oil and oxygen from the air. But if there is a lid, the metal could not be submersed into oil. The contradiction is: "There is a lid and there is no lid".
Using Inventive Principle in Resolving Contradictions module in Goldfire [12], the following possible solution is generated.

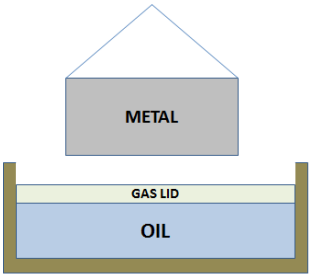


Figure 3. Adding gas lid to oil container [9, 10, 11]

Solution
Method - Apply a gas lid to cut off oxygen supply – Using the Principle of Phase Transition**.**
Advantage: By applying gas an invisible lid is created. There is no physical barrier to block the crane from moving. This innovative idea solves the contradiction that "there is a lid and there is no lid".
If the gas is heavier than air it stays on the top of the oil surface creating an invisible lid.

Example 3. Car tires breaks on pavement in winter.
In winter time in snowy climate, cars' tires (system No.1) will get cold, which makes rubbers less elastic and hardened. The hardened tires are slippery and easier to be broke by friction between tires and pavement [10, 11]. Introducing the substance between the tire and pavement is the usual solution for this problem [10, 11]. The IS however could be introduction of additional set of elements (electric wires) into the system No.2 – the pavement [8]. If the solar energy could be supplied this solution could pass an energy optimization test.

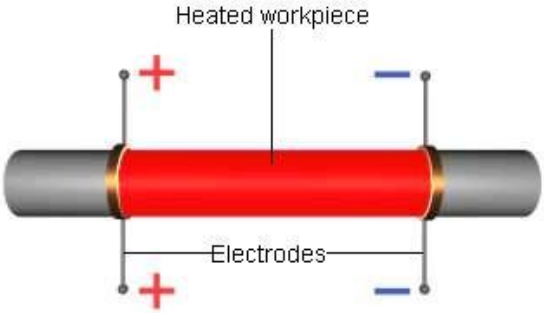


Figure 4. Electric wire to heat materials [8]

To prevent tires break in winter, new tires materials can be used to make special winter tires. This however is not the satisfactory solution since there are millions of cars operating on highway. It is costly and complicated to change tires in all cars operating during the winter. It is easier to improve the highway's pavement. Inserting heating wires (Figure 4) into the pavement is an Ideal Solution. The wires supply heat into the pavement, improve breaking action, and have no negative effects on the tires.

6. Conclusions

There are still no ideal systems for satisfactory solution of problem solving in Engineering Conceptual Design. There is a need for a system on which teaching could be based. BTIPS is proposed to become such a tool. Engineering by nature is a problem solving profession so all engineering students should take problem solving courses during the freshman year. Problem solving is also the important subject to which the candidates for engineering studies in high schools should be also introduced. It would be beneficial if BTIPS would become a tool to fulfill such a task. The important factor in teaching is use of the software. In spite of the fact that the programs supporting the conceptual design operation have limitations, some systems are useful. It seems that Invention Machine (now IHS) origin software is still the most useful tool for solving problems in engineering conceptual design, especially those with contradictions. It supports nonconventional approach in education, research and engineering practice in which the four

different phases of matter can be used in design. BTIPS was created to be a teaching tool. Seeking the Ideal Solution it refers first to the experience and global collection of known solved cases but also suggests the ways of further search for solutions. This way it can be used as a starting point for development of a new still unknown method of conceptual design. To advance conceptual design knowledge further, a broader education action should be undertaken. It is a strong hope of the author of this paper, that BTIPS could be the helpful teaching tool in the broad engineering problem solving education. The details of BTIPS history, capacity, structure and application can be found in references [1, 2, 3, 8, 9, 14, 15, 16].

7. Acknowledgement

This paper is a result of author's studies with participation of University of Connecticut Mechanical Engineering and Management Engineering for Manufacturing students and some faculty. The author would like to acknowledge their help as well as support from the Connecticut industry. Thanks are extended to former Invention Machine Corporation for the grants of IM v. 2 for Windows and the TechOptimizer software. Thanks to HIS for the Goldfire software system that was used in preparation of some examples. Many thanks to Dr Valery Tsourikov for his encouragement and help to start the research on development of BTIPS. Profound thanks are extended to the University of Connecticut School of Engineering computer laboratories leadership and staff, especially Stephen White, for his help in solving software problems during preparation of this paper. The author is grateful to the TRIZ Future Conference Organizers for creating a forum for discussion of problem solving methods in engineering conceptual design that are originated or connected with TRIZ. A sincere gratitude is owed to Katie Kornacki of Willimantic Connecticut for editing this paper.

8. References

[1] Bzymek Z.M. Rngineering Problem Solving - Learning and Practice, Proceedings of the InternationalMechanical Engineering Congress and Exhabition IMECE 2012, November 9-15, 2012, Houston, Texas, US

[2] Bzymek Z. M. Xu Y. „Effectiveness of the Problem Solving Software in Engineering Conceptual Design" IMECE 2012 – 86495, Proceedings of the InternationalMechanical Engineering Congress and Exhabition IMECE 2012, November 9-15, 2012, Houston, Texas, US.

[3] Sigmund Freud, Mediziner, Begründer der Psychoanalyse, http://www.dhm.de/lemo/html/biografi,en/FreudSigmund/, visited on 9/16/2015.

[4] Osborn Alexander Fainckey, Applied Imagination. Principles and Procedures of Creative Problem-solving, Third Revised Edition, Charles Scribner's Sons, New York, 1963.

[5] Altshuller G.S., Creativity as an Exact Science: Theory of the Solution of Inventive Problems, Gordon and Breach Publishers Inc., New York, 2nd Edit, 1987

[6] Ideation – General breakdown ideas today |futurethink.com 17 tips & trick to get you started. www.futurethink.com/ 5/30/2014.

[7] Tsourikov V. M., 1994, IM Course Notes, Invention Machine, Cambridge, Massachusetts.

[8] Bzymek, Z. M., 2000, Conceptual product Design Using BTIPS, DE Vol.109, recent Advances in Design for Manufacturing (DFM), ASME 2000, pp. 139-147.

[9] Bzymek, Z.M., 2005, "Brief Theory of Inventive Problem Solving—Enhanced Approach Using Principles," Innovations 2005—World Innovations in Engineering Education and Research, (A. Wing et al., eds.), International Network for Engineering Education and Research (iNEER), Begell House, pp. 503–516, 2005.

[10] Invention Machine™ v.2.1 for Windows. Principles, Effects, Prediction. User Guide, August 1995, Invention Machine.

[11] Invention Machine Corporation, 1998, TechOptimizer, Version 3.0, Invention Machine Corporation, 200 Portland Street, Boston, MA 02114-1722 USA, www.inventiomachine.com (visited 6/20/2013)

[12] IHS Award http://inventionmachine.com/invention-machine newsroom/bid/74688/Frost-Sullivan-Honors-Invention-Machine-with-2011-Global-Innovation-Management-Award (visited 6/20/2015)

[13] Suh Nam, The Principle of Design, 1990, Oxford University Press, New

[14] Bzymek, Z. -M.: New Principles in Conceptual Product Design Using BTIPS, Proceedings of the Fifth International Workshop on Advanced Manufacturing Technologies, London, Canada, (L. Wang and X.Y. Liu, eds.), Sponsored by National Research Council of Canada—Integrated Manufacturing Technologies Institute, pp. 105–110, 2005.

[15] Bzymek, Z. M., 2000, Conceptual product Design Using BTIPS, DVol.109, recent Advances in Design for Manufacturing (DFM),ASME 2000, pp. 139-147.

[16] Bzymek Z.M.: "BTIPS-Effects", (in Polish), Proceedings of the L Scientific Conference of the Engineering Committee of the Polish Academy of Science and the Scientific Committee of Polish Association of Civil Engineers "Krynica 2004", 12-16 September, vol. V, pp. 81–86, 2004.

[17] Seonmin Kim; Victoria Jane Mabin; John Davies (2008). "The theory of constraints thinking processes: retrospect and prospect". International Journal of Operations & Production Management (Emerald Group Publishing Limited) **28** (2): 155–184.

[18] What is TRIZ, TRIZ Journal**,** http://www.triz-journal.com/whatistriz_orig.htm (visited 6/20/2013)

Aspects of Teaching TRIZ

Christoph Dobrusskin

Philips Innovation Services, High Tech Campus 7, 5656AE Eindhoven, The Netherlands

E-mail address: c.dobrusskin@philips.com

Abstract

Teaching TRIZ in an industrial environment commonly poses an interesting dilemma. On one hand the time to explain the concepts and ideas of TRIZ is limited, while on the other hand the amount of topics to be taught is large and, to really understand and be able to apply TRIZ, a lot of time should be spend in exercising the TRIZ tools and concepts. The same dilemma exists, generally in an even exaggerated form, when teaching TRIZ to students and teachers in secondary schools. Based on experiences in teaching at schools, the present paper discusses avenues of overcoming some of the basic limitations that are encountered when teaching within a tight timeframe and the relevance of these to teaching in Industry.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: TRIZ, Education, Teaching, Industry, Schools, Secondary Education

1. Introduction

One of the most persistent dilemmas teachers of the "Theory of Inventive Problem Solving" (TRIZ) are facing when teaching TRIZ in an industrial environment is the fact that, on one hand, the time to teach TRIZ, is limited, while on the other hand the amount of topics to be taught is large. Most students in Industry have studied an engineering science for three or four years at least, some significantly longer. For learning TRIZ, which sees itself as the "Technology of Creativity"[1] the time is limited to a miserly three, five or ten days [2] depending on the proficiency level of the training.

In our experience, the situation is even worse in secondary education where topics such as TRIZ are often only taught as an afterthought and must somehow be integrated within the study of the "real" topics such as history, biology or art.

About two years ago, together with some colleagues from Royal Philips I got involved with the teaching of creativity and TRIZ at schools in the Eindhoven area. This within the framework of Jet-Net, an organization that is sponsored by Royal Philips and brings together leading Dutch technology companies and secondary (pre-college) schools with the aim of: "…providing students with experiences that show that technology is challenging, meaningful and socially relevant" [3]. Based on these experiences in teaching at schools, the paper discusses avenues of overcoming some of the basic limitations that are encountered when teaching within a tight timeframe and the relevance of these to teaching in Industry.

2. Aspects of teaching in secondary (school) education

While there appears to be a reasonably large base of papers, articles and books concerned with teaching TRIZ to school children in the Russian language [4], little if anything has been translated to English. Subsequently, for training in schools no widely accepted structure to teach TRIZ was identified, and training material was largely based on material available for teaching TRIZ in Industry.

In our experience, the time constraints in schools are extremely stringent, with sessions lasting from less than one hour to a maximum of one day. The primary focus of our TRIZ teaching activities was therefore to demonstrate firstly that creativity and TRIZ can be taught, and then to teach the "way of thinking", rather than over-emphasizing the use of specific tools. Depending on the nature of the engagement, which sometimes involved teaching students directly and at other

times meant teaching the teachers, and furthermore depending on the topic under consideration a selection of different generally easy to learn and to apply TRIZ tools were employed.

Over time we developed a number of specific strategies to deal with the time constraints so that we are able to teach as many concepts as possible, in the shortest possible time with the greatest possible impact.

Right from the beginning we started our training session for secondary schools by asking the class to perform a simple task. The task is introduced by the teacher with a sentence like: "I am your customer, could you draw for me on a piece of paper … (any simple task will do)". Naturally the assumption of the students is, that by simply doing what is asked for, the task will be well done. So everyone is taken aback when, after the collection of the results it is announced that they failed. The reason given is that no-one asked any question, so no-one knows what the customer – the teacher – really wanted. Only 2% of all participants in trainings that we have given the task, and there have been hundreds, have ever asked for any clarification when the task is given!

But the implications of this first task go further. The way of teaching in a school environment often is rather rigid. The pupil is given a task with all variables (engineers would say "requirements") clearly defined, all he or she has to do is to add up the numbers with the right formula and the correct result pops out at the end. In real life there are few such "closed" problems [5], and "open" problems have to be tackled in a different way, requiring a much more inquisitive mindset, one where one constantly has to challenge assumptions and to ask questions. In this way the exercise breaks the mold of habit, and prepares the student to ask questions beyond his or her usual scope. In more general terms the exercise "shakes" the participants awake as they realize that the training is not just about listening but demands thinking and active participation as well.

Immediately after the initial question we ask the students to find the correct answer to a more specific formulated task. The correct answer depends on information not yet given and students have, again, to pose the right questions. Most often they now catch on to the spirit of the exercise – with or without prodding provided by the teacher.

Throughout these exercises the students who ask clarifying questions are rewarded with a small token price, re-enforcing the message that it is important to be curious and explore the boundaries of the tasks at hand.

With time we have realized that the exercise is also an excellent introduction to ideality. After all, it is impossible to provide or improve any function or benefit without knowing the needs of the customer. Indeed, this is one of the basic notions not only of TRIZ, but of successful innovation in general.

When the concept that everyone can be an inventor is introduced to either secondary school students or their teachers, they generally meet the idea with some apprehension, similar to the skepticism that the originator of TRIZ, Genrich Altshuller must have faced when he first tried to popularize TRIZ [6].

To us, the easiest way to demonstrate the inventive power of TRIZ is to use simple exercises. One of them, for example, is based on a selection of inventive principles. To actually teach and demonstrate the use of all 40 inventive principles to secondary school students in the limited time available is impossible, so we start by introducing a selection of the "most used" inventive principles. Although one could derive them from TRIZ related literature [7, 8], we have opted to base the selection on our own experience as the principles have to be easy to understand without technical knowledge, and also can be pre-selected to be particularly suited to a given task. Inventive Principles that we have used include:

01. Segmentation
02. Taking out
03. Local quality
04. Asymmetry
07. Nesting
13. The other way round
17. Another dimension
25. Self-service

The selection of principles is briefly explained using examples from a wide variety of fields. While TRIZ was originally aimed at solving technical problems, increasingly it is also used in other fields, and a brief search will reveal a rich source for non-technical examples being available for each of the principles [9, 10, 11]. It has proven important to visualize each example of an inventive principles, and also to choose examples that are well known to the students, as this makes it easier for them to understand and recall the examples quickly. Fig. 1. shows an example illustration tailored to the Dutch culture. "Eten uit de Muur" translated "Food from the wall", is a typical Dutch sight in pedestrian shopping areas where hot meals can be bought from vending machines, and it serves as an illustration of Inventive Principle #25, Self-service.

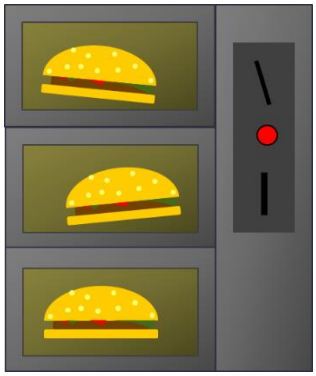


Fig. 1. An example illustration for Inventive Principle #25, Self-service: "Eten uit de Muur"

To further the understanding of what the inventive principles mean, and if there is sufficient time, students may then be asked to come up with a few examples of their own for one or more of the inventive principles.

Once the inventive principles have been sufficiently introduced, we explain to them how to create new ideas and solve problems. Taking a simple product from our daily environment as an example, we explain to them how to recognize existing problems, how to identify the resources that

are present in those products, and finally how to use the inventive principles to solve a problem or create new ideas. The students are then divided into small workgroups and they are each given a simple product as a starting point for an innovation exercise.

This exercise works best using everyday objects that are familiar to the audience, such as shoes, schoolbags, or chairs. When teaching the teachers we have also successfully used more complex problem situations, such as the problem of too few parking places being available at their school.

Our main learning was the fact that even considering an extremely restricted timeframe one can explain and demonstrate the power of the systematic inventive approach that TRIZ is advocating by concentrating on a few simple and powerful examples. In one session in which we introduced TRIZ to approximately 80 teachers, we managed to explain this way of working including a practical exercise with everyone in just over 30 minutes. We used a humble shoe as an example, and the participants were enthusiastically bending over the tables deep in discussion, holding their shoes in their hands to demonstrate and explain their ideas.

When we introduce TRIZ to teachers we often are asked about the relevance of TRIZ to their respective subjects, be it History, Biology or Art. In response we have designed our examples and exercises deliberately to accommodate such a wide variety of subject matter. We have found it important to prepare a shortlist of examples for each subject prior to the training, and experienced that even with a rather brief shortlist the relevance of TRIZ to a large variety of subject matter can still be convincingly shown.

One approach of introducing the Inventive Principles for any subject matter is for the teacher to explain one or more inventive principle, and then to ask the students to identify examples of the principle at work in the specific subject. Take for example Inventive Principle #1, Segmentation:

Examples of the use of this principle in history:

- The separation of countries in response to conflict: North and South Korea; the building of the Berlin wall.
- Structuring of the population: caste system in India; Nobles and Commoners; Free men and Slaves.
- Governance models: independence (or not) of Legislative, Executive, Judicative.

Examples of the use of this principle in biology:

- Defense strategies of lizards: separate the tail when threatened.
- Structure of vertebrae in mammals to allow movement.
- Hunting strategies of Lions in Africa, some run after the prey, others wait in ambush.

Examples of the use of this principle in Art:

- Structure of storytelling, chapters in books [12].
- Use of triptych in painting to tell different aspects in time.
- Modern painting, separation of planes, form and color.

In a next step, one can easily set different, more explorative tasks for students. The students are asked to use the inventive principles to solve problems:

- What options can you devise considering the current situation in country X?
- What other strategies but losing its tail could the Lizard employ to avoid being caught?
- When you look at the art of painting, what other separation principles could be applied?

While the initial task is an excellent one to foster the familiarization with the inventive principles, the latter task is much more playful, and generally tends to kick start creative outbursts. The collection of good examples, of suitable tasks (and clear teaching material in general) is of crucial importance, as the teaching of TRIZ and creativity, ultimately, will be the job of the teachers in their daily work, without the help of TRIZ specialists at their side. As a first step in that direction we have formed a working group together with teachers from a variety of schools to create and test this teaching material. While the TRIZ tools are generally applicable, to demonstrate their validity it is important to have good illustrative material that is relevant to the subject matter at hand.

A final remark, and perhaps an obvious one is the importance of humor that should be included during the training sessions. The relationship between TRIZ and humor has been shown for some time [13], and a number of recent publications [14, 15] have made ample use of it in clarifying and visualizing the concepts of TRIZ to both children and adults alike. We integrate these concepts into our teaching in the form of cartoons and stories.

3. Discussion

For training in Industry we predominantly apply the method advocated by the International TRIZ organization (MATRIZ) [2]. In this method the level of knowledge is build up in consecutive classroom training sessions, starting with three days (Level 1), moving on to five (Level 2) and finally ten days (Level 3). Teaching beyond Level 3 is on project level and not in classrooms. Each of these training sessions has its own allocated number of techniques that have to be taught for certification. The structured way of teaching has found favor with industry as it guarantees some quality and comparability of TRIZ education globally, and it is widely accepted in large corporations. We have found that our learnings from teaching in secondary school education comfortably fit within the MATRIZ framework.

Sometimes these learnings can be applied one on one, whereas at other times they have to be adapted to the specific environment or circumstance of training in industry. Overall they include the following:

- Interlace learning aims in the context of a specific tool or exercise
- Opening questions at the beginning of an exercise / project
- Use concise concentrated exercises to introduce new concepts
- Prepare and tailor examples to specific fields
- Use humor and storytelling

As with the opening question we use in schools, we pay specific emphasis to interlace learning aims of a "specific tool" with the "thinking behind TRIZ". This approach offers a number of distinct advantages:

- Many different topics can be explained within a short time, and the depth of teaching can easily be expanded if and when the need arises.
- Students are early on introduced to a wide variety of topics, topics they then can easily recognize and place later on in the course.
- Topics that have already been covered in some depth can be rehearsed later on.

And similar to the opening question used in schools, the question asked in a professional setting is used to find the facts behind the assumptions that stand at the beginning of any project. Often, rather than solving an apparent engineering problem, questions to a customer may reveal much "better" underlying problems and opportunities.

Based on our experience in secondary education we increasingly integrate the use of short concentrated exercises throughout the training program in industry, and particularly when introducing new concepts. A concise task within a pre-determined structure makes it easy for the student to concentrate on the subject at hand in an otherwise perhaps confusing world of new concepts. A further advantage is that the task is tailored to the tool and thus allows for a smooth step by step learning exercise.

While questioning the relevance of TRIZ for a secondary school topics like History or Art is understandable, similar questions remain valid with respect to different engineering disciplines, in industry; think for example of the software field where traditionally TRIZ has few examples. And the learning that preparation and tailoring of examples and cases to fit the subject matter remains an essential ingredient to better fit the TRIZ teaching to those target audiences also in industry. This required us to build up a repository of examples, which can be used to explain the concepts in many different engineering contexts. In parallel we developed a range of context dependent case studies and tasks for the student to solve during the training. And finally, to visually re-enforce the message, the examples are amply illustrated.

Finally, but perhaps not surprisingly, the lessons learned in secondary schools about the use of being playful, humor and storytelling have also found a fixed place in the teaching activities in industry. Playfulness keeps the interest. Humor is excellent in breaking up tension, and make points in a lighthearted way. Storytelling helps with the transfer of complex subject matter in a concise format. Also, recalling of sometimes complex subject matter can greatly be enhanced.

4. Conclusion

Teaching both pupils and teachers in secondary education has been a rewarding experience as it forced us to focus our teaching activities on the core matters and to express them in the most concise way. And many of the learnings from this activity have an equal validity for teaching engineers in an industrial context. Benefits of the application of those learnings include:

- A more effective way of learning
- A better way of teaching complex concepts
- More fun for all participants

Acknowledgements

The author would like to thank his colleagues Hans Baaijens and Per Mans, for the support, ideas and discussions while working on teaching TRIZ and creativity to secondary students. Special thanks also go to Anja Welvaarts and Jos Nelis, the Jet-Net coordinators for their support and organizational wizardry. Furthermore many thanks to Pascal Sire for talking to us about his experience at schools in France and MATRIZ for their support of that activity. And last but not least a big thank you to all the teachers, students and participants to the training from the various schools, your questions and responses are invaluable!

References

[1] Altshuller, G. The Innovation Algorithm. 2nd ed. Technical Innovation Center, Inc. Worchester, MA; 2007.
[2] MATRIZ, Certification requirements, Appendix 1, Required TRIZ knowledge standard for applicants to be certified as "TRIZ user" for levels 1 – 3; http://www.matriz.org, June 2016.
[3] For further information see: Jet-Net; http://www.jet-net.nl/english, June 2016.
[4] Guin, A. Barkan, M. Success Factor, Teaching creative thinking skills. Performance Press, Oak Ridge, TN USA; 2015. p 79
[5] Guin, A. Barkan, M. Success Factor, Teaching creative thinking skills. Performance Press, Oak Ridge, TN USA; 2015. p 11
[6] Altshuller, G. 40 Principles, TRIZ Keys to Technical Innovation. Technical Innovation Center. Worchester, MA; 2005
[7] Savransky, S. Engineering of Creativity. CRC Press LLC, USA; 2000. p228
[8] Heere, P. et. al. Doelgericht Vernieuwen. SDU Uitgevers bv, Den Haag; 2005
[9] Altshuller, G. 40 Principles, TRIZ Keys to Technical Innovation. Technical Innovation Center. Worchester, MA; 2005. p 99
[10] Mann, D. Systematic (Software) Innovation. IFR Press. Bideford, UK; 2008. p 417 - 460
[11] Souchkov, V. TRIZ and Systematic Business Model Innovation. in Proceedings of Int. Conference TRIZ Future 2010, Bergamo, p. 189-198.
[12] Altshuller, G. 40 Principles, TRIZ Keys to Technical Innovation. Technical Innovation Center. Worchester, MA; 2005. p 25
[13] Mann, D. Disruptive Advertising: TRIZ And The Advertisement. The TRIZ Journal; https://triz-journal.com/disruptive-advertising-triz-advertisement/; 2002.
[14] Ivanov, G. Dennis der Erfinder. Perspektivenverlag. Kösching, Germany; 2013.
[15] Gadd, K. TRIZ for Engineers. John Wiley & Sons, Ltd. UK; 2011

Conceptual framework for marketing communication management with a qualitative and system-oriented approach

Joanna Kijewska[a]*, Marek Goliński[a]

[a]*Faculty of Engineering Management, Poznan University of Technology, 11 Strzelecka Str, 60-965 Poznań, Poland*

* Corresponding author. Tel.: +48 61 665 33 74; fax: +48 61 665 33 75. *E-mail address:* joanna.kijewska@put.poznan.pl

Abstract

The objectives of marketing, in analogy with other science disciplines, can be classified into two main categories. The first one, the cognitive objectives (such as theoretical, scientific, modelling), reflects the necessity to acquire and collect the complex knowledge about the marketing exchange relations between the market entities. The second one, the practical objectives (such as engineering, constructive, normative), reflects the quest for practical methods for the rational (i.e. efficient, aggregating effectiveness, agility, energy usage and economic issues) operational marketing activities. The broad marketing literature has proposed a large variety of theoretical concepts. On the other hand, practical methods and tools for the marketing have expanded dynamically. However, the theoretical background and the practical applications in the field of the marketing management are not really connected. Consequently, practical tools do not exploit the entire potential of theoretical studies and furthermore incoherencies may arise. The aim of this paper is to relate the theoretical marketing concepts with the engineering procedures through the system thinking framework to face the problem of qualitative and systematic approach to marketing management. These assumptions are used in scientific research. Firstly, marketing is defined and the subsystem of marketing communication is selected for the further research. Secondly, the perspective for the systematic thinking concepts and methods application to the marketing communication management is considered. The qualitative operations and OSTM-TRIZ modelling is applied for the marketing communication research. Finally, the System Operator model of TRIZ thinking is adopted to combine the notions used in different systematic thinking theories and methods. The framework of the integrated marketing communication management with a system-oriented approach is proposed. The conducted research shows to have the potential of overcoming the two main difficulties of modern marketing, such as harmonic and systematic marketing management and the knowledge extraction form the marketing data.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Marketing management, quality, OTSM TRIZ modelling

1. Introduction

Current conditions for business activity are characterized by the advancing integration and globalization, an increase in competition intensity, networking and IT implementation. These phenomena increase the complexity and complication of conditions for business activity, as well as the dynamics of business changes. The new problems of the marketing activities of currently operating businesses emergence, such as [1]:

- integrated approach to marketing in the perspective of time horizons as well as the elements and structure of marketing itself;
- market orientation and management of relation network with varied groups of market entities, mainly with customers, deliverers, competitors, representatives of the government, education and science, research organizations;
- relations of marketing with other business activities, spreading tasks and marketing issues to all organization units, and linking marketing functions with other functions of a business;
- extracting knowledge from marketing data, the problem of usefulness and effectiveness of dealing with a lot of data as well as adapting them to the needs and cognitive possibilities of their recipients.

Several concepts relating to the above problems can be distinguished in the broad marketing literature. In the concept of marketing mix [2, 3], marketing is represented as a set of components, and marketing manager is "a mixer of ingredients, who sometimes follows a recipe as he goes along, sometimes adapts a recipe to the ingredients immediately available, and sometimes experiments with or invents ingredients no one else has tried" (Culliton, 1948 in: [4]). The system-oriented approach to marketing [5] indicates a possibility to refer to the general theory of systems in research and solving problems of marketing. System-oriented approach is developed in current concepts of marketing. Relationship marketing [a.o. 6, 7] focuses on examining the relations of a business with the market surrounding. The integrated marketing communication, IMC [a.o. 8] reflects and examines elements of the marketing mix, in particular promotion and marketing communication, in the holistic approach.

The literature analysis shows that most research covers the area of marketing relating to the principles of marketing, i.e. to the scope of knowledge concerning elements of the marketing mix and their relations. There are still rare cases of research referring to methods and tools of managing elements of the marketing mix in the holistic approach, i.e. marketing management. The objective of the research carried out is to recognize the possibilities of creating methodological guidelines for designing methods of managing the quality of marketing activity in a system-oriented approach, i.e. considering the quality of its elements and their relations. The selected subsystem of marketing activity which is of particular focus, as the subject of research, is marketing communication.

2. The concept of marketing communication

The fundament of social life is communication - transmission of messages between entities [9]. The development of its complexity and efficiency influences the shaping of human personality, conditions for collective life, culture, science, economy [10].

The broad literature of marketing defines the concept of marketing communication in various ways and there is no generally accepted coherent and unambiguous definition of marketing communication. It is frequently identified with promotion [11]. Other approaches show that marketing communication is a wider category than that of promotion – it refers only to delivering marketing messages to the market, and communication is a process of sending and receiving marketing messages [12]. There are also concepts distinguishing between marketing communication and promotion [13].

In research, marketing communication describes a transmission of marketing messages, i.e. messages about a chosen piece of the surrounding market, among business units of the market entities. In a unitary approach, that marketing messages transmission is called the marketing communication process. In a general approach, marketing communication of a business is a multi-subject network of complex activities, consisting of numerous, various processes of market communication and relations taking place among those element [9].

3. Chosen concepts of system-oriented approach

The paper assumes the system-oriented approach to the object of research, namely the marketing communication. The general principle of the theory of systems, i.e. the existence of the character of the general system [14], is adapted. From the methodological perspective, the research relates to principles of TRIZ – the Theory of Inventive Problem Solving. The Theory of Inventive Problem Solving (TRIZ) is used by scientists and practitioners of many different areas of science. This theory was developed by Genrich Sualovich Altshuller between 1946 and 1998 [15]. Its objective is to help the inventor in the most effective way to use their knowledge and experience, and in further stages to enable the integration of collective efforts of inventors [16].

TRIZ methods and tools are already well known and used in technology and engineering, as "TRIZ was created by engineers for engineers" [17]. However, the author of TRIZ points out that principles of guiding the thinking process while solving invention-related tasks (principles and not particular formulae or rules) may be transferred to other areas and used to organize creative thinking connected with any area of human activity [16]. Seeing objects of research as generic models enable to apply TRIZ scientific methods to various problem areas. The identified list of examples of TRIZ application [18] includes such areas as technical, architecture, software development, chemical engineering, construction engineering, condition monitoring of machines, and other, non-technical problem areas, e.g. education, customer satisfaction, ergonomics, public health and social science. The TRIZ methodological principles and techniques have been applied in the field of management science [19, 20], quality management [21, 22, 23, 24] and also in the field of marketing [25, 26, 27].

Research described in this paper created a conceptual framework for the use of classical reference TRIZ model of system thinking (System Operator) and the model of contradiction in quality management of marketing communication. The method successfully combines two scientific areas:

- qualitology, science dealing with quality, which is used for the qualitative modelling of the object of research;
- OSTM-TRIZ modelling tool, i.e. the model of contradiction, which is used for designing qualitative changes of the research object in the holistic approach.

Further chapters present aspects of qualitative modelling and the core of the concept of OSTM-TRIZ modelling tool, i.e. the model of contradiction.

3.1. Qualitology and the category of quality

Qualitative methodology of object modelling is the subject of research of qualitology, the quality science. Polish literature, in view of incoherence and variety of classification of theoretical discussions on quality aspects, suggested the concept of holistic organization of existing knowledge about quality [28]. The main objective of qualitology is 'to create scientific principles of qualitative cognition and qualitative shaping of reality by man' [29]. The assumption of the qualitative approach in modelling objects consists in accepting

qualitative categories for the modelling of the core of the object, in the following aspects:

- descriptive, ensuring full identification (recognition) of the quality of the object modelled;
- comparative, allowing to refer to and compare the quality of the modelled object with that of other objects;
- axiological, enabling evaluation of the object [30].

In qualitology, the nature of objects is identifying by the categories of quality and attributes, and it is assumed that attributes and quality belong to objects. The quality of an object is defined as follows:

Definition 1. The quality of an object (p) is **the set of attributes** (ci) belonging to it [29]

$$J^p = \{c_1^p, c_2^p, ..., c_n^p\} \quad (1)$$

Definition 2. The state (s) of quality of an object is the set of **the states of attributes** belonging to it [29]

$$J_s^p = \{s_{c1}^p, s_{c2}^p, ..., s_{cn}^p\} \quad (2)$$

Evaluating quality, based on the axiological criterion of value, is done by examining the set of the states of attributes of the object in view of a chosen criterion of value (e.g. effectiveness of satisfying needs, meeting requirements). Quality of evaluation defines the so-called 'fitness for use' [31].

Assuming principles of qualitative perspective in modelling marketing communication it is accepted that the quality of marketing communication is the set of attributes belonging to it. Evaluation of the quality of the system of marketing communication consists in viewing the set these attributes and their structure towards accepted criteria of their value. In the conducted research, it was accepted that the criterion of value for the quality of the system of marketing communication is the effectiveness of satisfying the marketing objectives.

Managing the quality of the system of marketing communication consists in performing basic functions of management in reference to the qualitative categories of its elements and their structure [based on 29].

3.2. OSTM-TRIZ modelling and model of contradiction

The model of contradiction created within OSTM (the Russian acronym for General Theory of Powerful Thinking) provides a formalized approach to the identification of the contradictions between conflicting requirements for system evolution to the state of its ideality. The concept of contradiction is described by 3 types of components [15, 32, 33]: **the elements** (constituents of a system), **the parameters** (describe elements by assigning them a specificity; there are two types of parameters, **the active parameters**, which are under the designer control and their state might be modified by the designer, and **the evaluating parameters**, which reflect the results of the designer choice and their state is related to the state of the active parameters) and **value** (used to describe the parameters in the quantitative manner).

Reflecting the system of marketing communication in the contradiction modelling approach, the elements belonging to it are classified into two classes. The first class includes the elements that marketing managers have an influence on, and they are referred to as active parameters of the contradiction model. The other class includes the elements that managers do not have a direct influence on, and they are referred to as evaluation parameters in contradiction modelling.

Moreover, it is pointed that in modelling of a complex marketing system the integrated approach to the parameters of its elements and their relations is required. According to currently developed concepts, modelling of complex system with an integrated approach to the parameters relations is an attempt to reflect the network of contradiction [34] and assess them based on adequately defined criteria like for example importance, universality or amplitude of the particular contradiction [35].

4. Conceptual framework for systematic approach to marketing communication management

Since the general system theory was introduced, to prove a major step towards unification of science [14], many different concepts of system thinking, in various fields of study were introduced. In various perspective of system thinking, various lows and principles are accepted, and also various sets of notions are used. A certain perspective of system thinking is supported by a set of methods, techniques and research tools for the object study. The current state of development of marketing research in the marketing system approach has defined theoretical bases for the market modelling. However, there is still a lack of methods that would facilitate their practical application. In this research authors are trying to find how to combine methods of various concepts of system thinking in order to:

- provide marketing managers, who do not have the background knowledge related to the particular system thinking approach, with methods, techniques and tools of various concepts of system thinking; and
- ensure a proper identification of the object studied and use various models of this object in management activities of marketing managers.

The paper shows the possibility of using System Operator to combine the different concepts of system thinking.

OSTM-TRIZ system-oriented thinking tool System Operator enables creating models of objects in a systematic approach [15]. The structure of the object is identified, according to the general theory of system. It is done firstly through distinguishing those elements, which are systems themselves due to their complexity, called sub-systems. Secondly, through considering interaction of the examined system with the surrounding and it's belonging to another, superior system. The System Operator approach take into account the changeability of the system over time. This changeability is expressed in three perspectives. The first one refers to the evolution of a given system (historical time). The second one is directed at reflecting the cause and effect relationship of changeability of states of the system. The third one examines the changeability of the object in its individual states of life cycle [15]. The general model of System Operator is described in 3x3 matrix of 'screens', whereas in research arbitrarily extendible in any direction should be considered [15, 36].

Conceptual framework for the application of System Operator for the system-oriented marketing communication

management is proposed. Firstly, the object of research, i.e. the marketing communication, is related to the use of the general matrix of the System Operator. Secondly. Then, the System Operator matrix is defined according to the notional apparatus accepted in general models of qualitative modelling and in OSTM-TRIZ model of contradiction. As a result, the matrix reflecting the object of research in the systematic approach and in accordance with the notional apparatus of two different concepts of system thinking is proposed – Figure 1.

	General system model	The model of marketing	Qualitative modelling	OSTM-TRIZ modelling
	1 stage		2 stage	
	Past			Future
Supersystem	Supersystem	Marketing	Quality	Set of ENV
	System	Marketing Communication	Quality of an object	Elements
	Subsystems (or elements)	Marketing Information (IP approach)	Effect Attributes	Evaluation Parameters
Subsystem		Sender; Channel and Tools; Receiver	Cause Attributes	Active Parameters

Fig. 1. Integration of the systematic thinking methods through System Operator. (Source: own study based on [9, 36, 37])

The vertical axis represents the relations among the system elements and its surroundings. The horizontal axis represents the time and refers to the process view over time. The two-stage sequence of action of the evaluated research procedure is indicated. Marketing communication is defined by such elements as business unit in the function of the sender (Sender); the channels and tools of marketing communication (Channel and Tools); the business unit in the function of the receiver (Receiver); and marketing information which is transmitted and created through communication activities. The relations among the above-listed elements were identified. Marketing information was distinguished. Firstly, because the marketing managers do not have a direct influence on it. In the conducted research the information product approach [37] is assumed, where the two sets of characteristics (parameters, attributes) of information are defined. The first set is a set of characteristics dependent on man, where information is treated as the product of marketing communication related with the human thought. The other set is a set of characteristics dependent on the so-called process of information production, i.e. the process of marketing communication activities. Secondly, because marketing information determines the achievement of the cognitive and creative objectives of marketing.

The problem of marketing communication management, noted by the authors, is to recognize the quality of marketing communication and such a set of its characteristics that would ensure the efficiency in the fulfillment of marketing objectives. To face those problems, the qualitative modelling and the OSTM-TRIZ model of contradiction is proposed. The proposed System Operator matrix indicates which elements of marketing communication match which elements defined in the general qualitative model and the general OSTM-TRIZ model of contradiction. The System Operator matrix, marked in this way, is the basis for integration methods, techniques and tools of those concepts of system thinking which can solve certain problems of managing the system of marketing communication.

5. Conclusion

Combined experience of qualitative approach of marketing communication using OSTM-TRIZ methods is applied to increase the effectiveness of the system of marketing communication management. The concept of perceiving marketing communication, described in this paper, may be a significant criterion deciding about the flexibility of the company's marketing management. The company's ability to adapt to a new reality is the competitive advantage in the modern market. The concept of integration of the systematic thinking methods through System Operator described in the paper might extend the set of methods and tools applied in the marketing management activities. The concept is rooted in scientific methods. The practical application of the integration of the systematic thinking methods through System Operator in business practice is the perspective for future research.

6. References

[1] Mantura W., Rozważania o współczesnych problemach marketingu, Studia i Prace Wydziału Nauk Ekonomicznych i Zarządzania NR 39, T. 2, 2015, pp. 11-23

[2] Borden, N. H., The concept of the marketing mix, in Schwartz, G. (Ed), Science in marketing. New York, John Wiley & Sons, 1965, pp. 386-397

[3] McCarthy, E. J., Basic Marketing, IL: Richard D. Irwin, 1964

[4] Goi Ch.L., A review of Marketing Mix: 4P or More?, International Journal of Marketing Studies, Vol.1, No. 1, 2009, pp. 2-15

[5] Fisk G., Dixon D.F., Theories of Marketing Systems, New York, Harper&Row, 1967

[6] Grönroos Ch., The relationship marketing process: communication, interaction, dialogue, value", Journal of Business & Industrial Marketing, Vol. 19 Iss 2, 2004, pp. 99 – 113

[7] Berry, Parasurman, Listening to the Customer – The Concept of a Service-Quality Information System, Sloan Management Review, Spring, 1997, pp. 65-76

[8] Schultz D.E., Schultz H. F, Transitioning marketing communication into the twenty-frst century, Journal of Marketing Communications, 4:1, 1998, pp. 9-26

[9] Mantura W., Comperative analysis of the category of quality information, in: M. Goliński, M. Szafrański (ed.) Integrated support system for access to information in urban space with use of GPS and GIS systems, Publishing House of Poznań University of Technology, 2012, pp. 7-30

[10] Goban-Klas T., Sienkiewicz P., Społeczenstwo informacyjne: Szanse, zagrożenia, wyzwania, Wydawnictwo Fundacji Postepu Telekomunikacji, Kraków, 1999

[11] Kotler P., Keller K., Marketing Management, 14th Edition, Pearson Education, Inc, 2012, p. 510

[12] Andersen P.H., Relationship development and marketing communication: an integrative model", Journal of Business & Industrial Marketing, Vol. 16 Iss 3, 2001, pp. 167 – 183

[13] Rossiter J. R., Percy L., Advertising and promotion management. McGraw-Hill series in marketing, New York, NY, England: Mcgraw-Hill Book Company Advertising and promotion management, 1987

[14] von Bertalanffy L., General System Theory. Foundations, Development, Applications, George Braziller, Inc., New York, 1969

[15] Cascini G., TRIZ-based Anticipatory Design of Future Products and Processes, Journal of Integrated Design and Process Science, 16 (3), 2012, pp. 29-63

[16] Altszuller H., Algorytm wynalazku, Wiedza Powszechna, Warszawa, 1975

[17] Souchkov V, Breakthrough thinking with TRIZ for business and management: an overview, ICG Training & Consulting, 2007

[18] Cempel C., Inżynieria kreatywności w projektowaniu innowacji, Wydawnictwo Naukowe Instytutu Technologii Ekspolatacji – PIB, Radom-Poznań 2013

[19] Mann D., Application of TRIZ tools in a non-technical problem context, The TRIZ Journal, Aug, 2000

[20] Ruchti B., Livotov P., TRIZ-based innovation principles and a process for problem solving in business and management, The TRIZ Journal, 2001

[21] Wang FK., Chen KS., Applying Lean Six Sigma and TRIZ methodology in banking services, Total Quality Management, Taylor & Francis, 2010, pp.301-315

[22] Su CT., Lin CS., Chiang TL., Systematic improvement in service quality through TRIZ methodology: An exploratory study, Total Quality Management & Business Excellence, Volume 19, Issue 3, 2008, pp. 223-243

[23] Yamashina H., Ito T., Kawada H., Innovative product development process by integrating QFD and TRIZ, International Journal of Production Research, Volume 40, Issue 5, 2002, pp. 1031-1050

[24] Retseptor G., 40 inventive principles in quality management, The TRIZ Journal, 2003

[25] Zouaoua D., Crubleau P., Mathieu J., Thieblemont R. and Richir S. (2010) TRIZ and the Difficulties in Marketing Management Applications. 2010 Proceedings of PICMET '10: Technology Management for Global Economic Growth (PICMET), pp. 1–10.

[26] Mann D., Disruptive Advertising: TRIZ and the Advertisement, The TRIZ Journal, 2002

[27] Retseptor G., 40 inventive principles in marketing sales and advertising, AVX Israel ltd. Sawaguchi M., 2005

[28] Kolman R., Kwalitologia. Wiedza o różnych dziedzinach jakości. Wydawnictwo Placet, Warszawa 2009

[29] Mantura W., Zarys kwalitologii, Wyd. Politechniki Poznańskiej, Poznań 2010

[30] Mantura W., Kategoria jakości w projektowaniu technicznym, Wydawnictwo Politechniki Poznańskiej, Poznań 1994, p. 67

[31] Juran J., The Quality Control Handbook, 3rd ed., McGraw-Hill, New York, 1974

[32] Cavallucci D., Rousselot F., Evolution hypothesis as a means for linking system parameters and laws of engineering system evolution, Procedia Engineering 9, 2011, pp. 484–499

[33] Khomenko N., De Guio R., Lelait L., Kaikov I., A framework for OTSM?TRIZ-based computer support to be used in complex problem management, International Journal of Computer Applications in Technology, Volume 30, Issue 1-2, 2007, pp. 88–104

[34] Becattini N., Borgianni Y., Cascini G., Rotini F., Model and algorithm for computer-aided inventive problem analysis, Computer-Aided Design 44, 2012, pp. 961–986

[35] Baldussu A., Becattini N., Cascini G., Network of contradictions analysis and structured identification of critical control parameters, TRIZ Future Conference 2010, Procedia Engineering 9, 2011, pp. 3–17

[36] Cascini G., Rotini F., Russo D., Networks of trends: systematic definition of evolutionary scenarios, Procedia Engineering 9, 2011, pp.355–367

[37] Lee Y.W., Strong D.M., Kahn B.K., Wang R.Y., AIMQ: a methodology for information quality assessment, Information & Management 40, 2002, pp. 133–146

Developing Growth Portfolio with TRIZ Structures

Philip Samuel[1], Michael Ohler[2]*, Naresh Shahani[3] and Derek Bennington[4]

[1]*Chief Innovation Officer, BMGI, 1200 17th Street, Suite 180, Denver, CO 80202 USA*
[2]*Innovation Practice Leader, BMGI, Buchsbaumweg 6, 22880 Wedel, Germany*
[3]*General Manager, BMGI India, 905/906 Raheja Chambers, Nariman Point, Mumbai 400021, India*
[4]*Managing Director, The TRIZ Journal, 1200 17th Street, Suite 180, Denver, CO 80202 USA*

* Corresponding author. Tel.: +49 151 28415103. *E-mail address:* Michael.Ohler@bmgi.com

Abstract

Creative destruction is taking its toll on corporations. We live in an era where the rate of change for change itself is accelerating and the half-life of new innovations is growing shorter, demanding the ability to innovate time and time again at a faster pace. Globalization, changes in market trends, customer demands, and regulations and lower barriers of entry are causes of this acceleration. Companies must find new forms of differentiation by creating new products, services, processes and business models in order to earn their place in the market every day by becoming more agile, more innovative, and more adaptable. Developing a new portfolio of solutions that meets or beats expectations in the marketplace isn't an easy feat, and it's even more difficult to do on a sustainable basis. To ensure success, the first step is identifying a new portfolio of opportunities.

This paper discusses how TRIZ thinking can enable the identification and development of growth portfolios for innovations when used in tandem with Market Trends, Customer Insights and Technology Trends. The roadmap is the result of several years of portfolio identification projects carried out within a number of companies from a variety of industries. With the help of examples and case studies, we discuss the lessons learned, as well as best practices when integrating TRIZ with other strategy tools to develop a robust innovation portfolio.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Portfolio Identification, Opportunity Exploration, TRIZ Integration, Trends

1. Introduction

Revenue growth is number one agenda for most CEOs. Growth can be achieved through Mergers and Acquisition route or through new products, services and business models developed with the help of innovation. However, both approaches fall short of expectations, even when used in combination. Most executives agree that while innovation is preferred, it is difficult for well-established companies. By and large, they are better executors than innovators, and most succeed less through game-changing creativity than by optimizing their existing businesses.

The innovation researchers report that most innovations fail [1]. One of the problems can be tracked to poor management of the innovation process, starting with identifying a portfolio of opportunities for innovation and ending with commercialization or implementation [2, 3, 4]. Figure 1 provides an overview of the key innovation process cycles that must be managed and leveraged. There are four innovation cycles that companies must manage if they aspire to stay on their growth trajectories. Without all four, successful innovation efforts will remain an ambitious challenge.

1. Opportunity Exploration – In this cycle companies must explore the entire realm of innovation possibilities. It is an ongoing process of saturating,

incubating, and illuminating. This cycle is a key input to your growth and innovation strategy development.

2. Front End Innovation – In this cycle, we call the Rapid Innovation Cycle, companies and project teams use the D4 process (**Define** the opportunity, **Discover** ideas, **Develop** solutions and **Demonstrate** the feasibility) to advance prioritized innovation opportunities. The approach is highly dependent on direct customer interaction all along the way. Rapid prototyping and testing involving the end user is critical. Through multiple rounds of both quantitative assessments of the design and qualitative user experience testing, teams end up with an innovation solution ready for detailed design and commercialization.
3. Back End Design – In this cycle companies take feasible innovation solutions and perfect them. The focus of this cycle is developing and perfecting the design using a "Design for X" process, which takes a feasible solution and designs it for manufacturability and assembly, usability, reliability, durability, robustness, serviceability, maintainability, sustainability, etc. This cycle is typically managed through a phase-gated approach.
4. Commercialization or Operationalization – In this cycle the solution is delivered to the market for external customers or fully operationalized for internal customers. Change management, stakeholder communication, and revisions based on customer feedback are essential to the adoption of the solution and the success of the innovation.

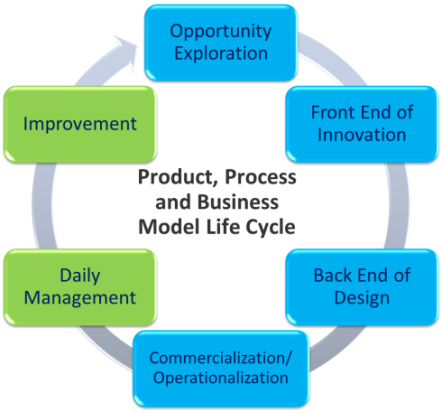


Figure 1: Innovation Process Life Cycle

The focus of this paper is on the key factors influencing Opportunity Exploration cycle. Organizations who understand and implement these four cycles realize a much higher innovation success rate than the ones following ad-hoc innovation processes.

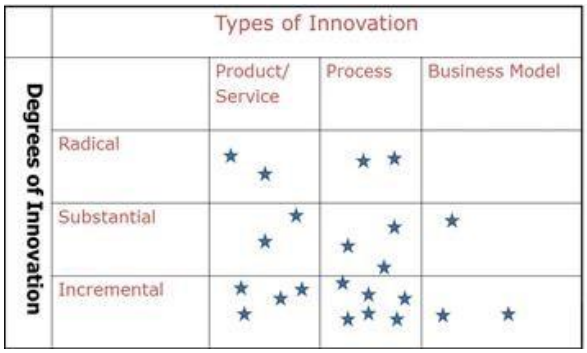


Figure 2: Innovation and Growth Portfolio

Opportunity exploration cycle drives organic growth and innovation strategy for the firm. It is the foundation of the strategic portfolio development for companies. The objective is to identify the right opportunities to develop new products, services, internal processes, and business models that will form the basis of the company's future. The deliverable is an exhaustive and comprehensive opportunity pipeline for the organization to pursue. This is depicted in Figure 2.

The inputs for this process include customer needs (aka customer Jobs-To-Be-Done), market and technology trends, regulatory changes, business capabilities, competitor moves, process/ technology/ human capabilities, company's aspirations/strategy as well as other external factor such as geo, political changes. Analyzing and prioritizing the best opportunities before embarking on innovation projects will help organizations:

- Directly align innovation efforts to your organization's strategy.
- Identify and prioritize relevant market trends and their implications for your growth and innovation portfolio.
- Develop insights into the most important and underserved customer needs or Jobs-To-Be-Done for each segment.
- Identify and analyze key technology trends and their implications for product and/or process innovation.

Of the input factors listed above, the three most important factors that affect portfolio identification are market trends, customer insights and technology trends.

The Theory of Inventive Problem Solving (TRIZ) has been effectively used during various stages of innovation. It has a set of robust techniques and methods for analyzing problems; identify contradictions; analyzing insufficient, harmful and excessive functions; and offering clever solutions from past designs from related or unrelated industries. However, there is an opportunity to link TRIZ techniques and tools to various innovation lifecycles including opportunity exploration during portfolio identification cycle. For the remaining part of the paper, we will highlight how TRIZ can enable managing market trends, customer insights and technology trends.

2. Market Trends

Developing strategy and driving innovation demands context. Context leads to insight; insight leads to ideas; ideas

are the substance of innovation. Researchers have analyzed recent innovations that have taken foothold in the market place and extracted a set of market trends that are prevalent. These trends have been categorized into mega, macro and micro trends. The process for managing and activating the trends are as follows:

Identification of the mega, macro and micro market trends impacting your customer segments. For example, “digitization” is a mega trend that is impacting most industries whereas “Internet of things” (a macro trend) and “biometric payments” (a micro trend) may not have immediate relevance to some industries.

- Clarity on the underlying drivers of change, such as change in consumer behavior and customer engagement, or change in the rising influence of social media.
- Completed Trend Relevance and Potential Grid to assess trends most important for your organization’s future.
- Living Trend Radar Map to stage and focus on the most important trends over time.
- Selection of the ten to twenty most important trends to drive your innovation opportunities.

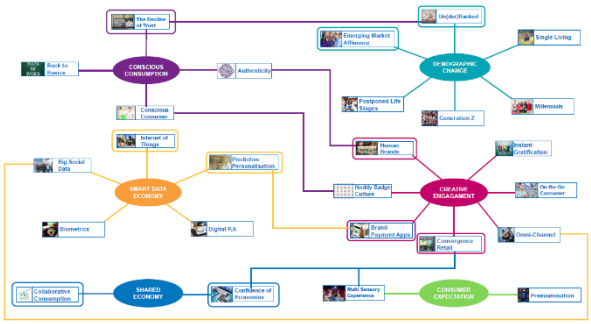


Figure 3: Sample Trend Relevance Map

Figure 3 illustrates a trend relevance map for financial services. We can see that many trends form contradictions in the way implement its solutions. For example, implementation of ‘predictive personalization’ trend can be in conflict with ‘decline of trust’ trend. This is where TRIZ thinking can help resolve.

The trend relevance map also guides the teams to consider its implications for future in terms of scenarios. Typical scenarios include base case, best case, worst case and rogue cases. These are analyzed for likelihood, impact and timing. Based on this analysis, an opportunity map can be created.

3. Customer Insight

Innovation at its heart is a process of seeking solutions to meet customers’ desired outcomes. According to noted psychologist Dr. Mihaly Csikszentmihalyi it is about applying creativity “to bring into existence something genuinely new that is valued enough to be added to the culture” [5].

The objective of customer insights analysis is to identify the jobs customers are trying to get done and categorize them in terms of under-served, served-right and over-served as shown in Figure 4. These determine potential strategies for action. For example, under-served opportunities are candidates for new ideas for innovation and served-right jobs might point us towards related jobs to be done. Similarly over-served opportunities are ripe for potential disruption in the market place if there are many non-customers struggling to get the job done.

TRIZ is used in this context in formulating the ideality and ideal final result in the context of the jobs customers are trying to get done. It also forces us to consider the resources available or needed to get the job done. This process will not rely solely on your internal perspective, but will directly involve input from customers, which will help you identify and select the most important product, service, process, or business model innovations to pursue.

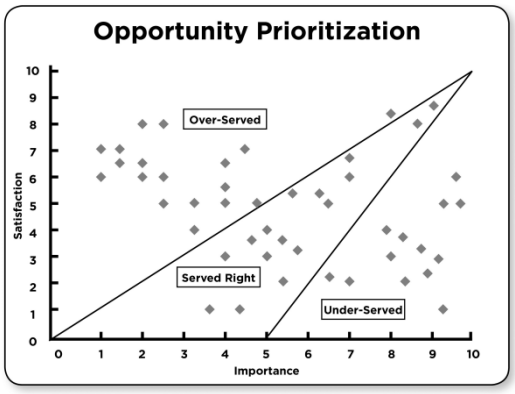


Figure 4: Prioritization of Customer Jobs-To-Be-Done

4. Technology Trends

Regardless of the industry an organization is active in, most businesses need to be selective when it comes to where it allocates development resources, such as R&D spending. Industry demand is strongly influenced by both prevailing market trends, i.e. what is popular with and expected by users and consumers, as well as to what extent current offering measure up to those expectations (customer insights). These inputs paint a picture around where the expected value in an offering or service should be, but does not directly impart knowledge relating to HOW to deliver on it.

Understanding the expected evolutionary path of a product or service, equips an organization with the opportunity to be selective in how it grows its portfolio. An organization’s own technology roadmap drives its development efforts, alongside being responsive and proactive when considering the activities and strategies of its competitors. In order to fully leverage knowledge arising from insights into technological evolution, an organization should answer the following questions:

- What is the value of current intellectual property (IP)?
- What IP may be at risk for disruption?

- What is the value of the IP published by competitors?
- How could competing IP be leveraged as a basis for enhancing an organization's competitive stance?
- Which technology trends are relevant to the organization's competitive position?
- Based on the laws of technical systems evolution, what is the maturity of current offerings and how can these insights be used to design and protect the next evolution of a technology?

4.1 Analyzing Intellectual Property

An organization's Intellectual property, as made available in public patent document publications, is an insightful source of information to determine the strategic direction an organization is taking its development efforts. Within patent documents, the claims section describes the exact nature of an invention and is the exact embodiment of the enforceable IP. By analyzing patent claims, it is possible to glean insight into both the current maturity of an invention as well as its future defensibility.

In general, patents may be categorized into the following broad categories [7]:

- Patents with low current value and low future value typically speak to a very specific embodiment of an invention, and will likely be easily susceptible to patent circumvention tactics and be unlikely to stand up to legal challenge.
- IP with high current value and low future value expands beyond just a specific embodiment of an invention, and will use language that covers current technology in use as well as variations thereof. However, these patents are at risk of being leapfrogged by new technology and do not use language that accommodate for improvements in technology or alternate strategies to achieve the same result.
- Patents with low current value and high future value contain language aware of future changes in technology. These patents are differentiated from the previous categories by virtue of the fact that they are expected to be difficult to challenge and circumvent.
- Patents with both high current and future value are the best performers in any patent portfolio. Their IP is represented aware of current and future technology evolution, and are well written to mitigate the risk of copycats and circumvention tactics.

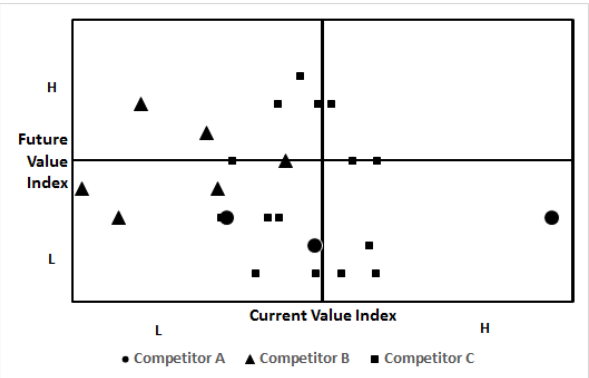


Figure 1: Intellectual Property Comparisons

This categorical designation affords an organization the opportunity to assess the strength of its IP portfolio relative to that of competitors (see Figure 5). Intellectual property that is poorly expressed in relative terms may be assessed for its potential and better protected with follow-up intellectual filings. Likewise, insight into which competing IP publications are currently being exploited in the market may lead to strategic efforts in order to ring fence technology with additional competing IP. If the next evolution of a technology is known, inhibiting the path of a competitor may enable an organization to establish themselves to be the first to market.

Next, two tactical techniques are presented which focus on mapping a number of publications in a comparative fashion to help identify opportunities.

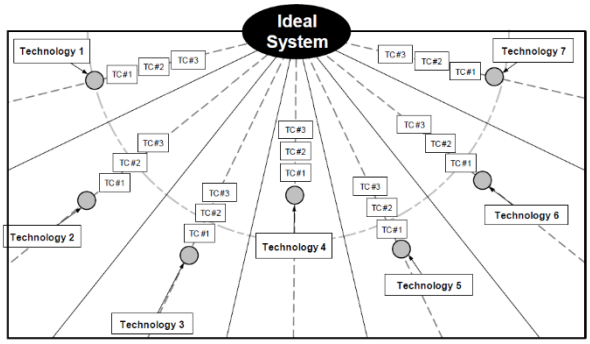


Figure 6: Sun Diagram Approach

The *Sun Diagram* approach [6], methodically maps out technical contradictions associated with competing technologies aiming to provide solutions to the same challenge or JTBD. Most IP, even those protected by patents, include trade-offs in order to realize practical solutions. Understanding these trade-offs and modeling them as contradictions, aid the practitioner in understanding which problems, if resolved, would advance the technology closer to the IFR. Likewise, having a firm grasp on which technical contradictions truly matter, presents an opportunity for the development of IP that prevents competition from advancing their technology and also introduces an opportunity for licensing IP to competitors.

The *Patent Landscape* analysis [8] is an example of mapping IP owned by competing organizations against categories. Categories include domains, patent claim coverage, system/solution components and more. Categories may be any set of designations applicable to the JTBD or problem under consideration.

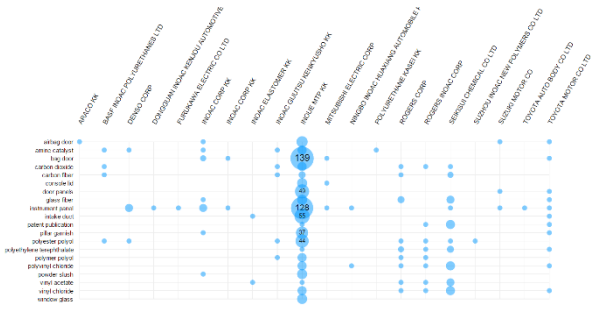


Figure 7: Patent Landscape Analysis

Figure 7 demonstrates that this visualization provides a summary of organizational focus and activity relative to the chosen categories. Areas of high activity will quickly emerge and be in contrast to white space, which could potentially identify niche applications as well as emergent opportunities. Market trends and customer insight would substantiate of white space areas truly represent valid opportunities (see [9]).

4.2. Laws of Technical System Evolution

The laws of technical systems evolution dictate that systems evolve to an increased state of ideality where ideality =benefits/(cost+harm). The evolutionary direction is always towards the ideal final result (IFR). The TRIZ IFR concept is exceptionally powerful, as it encourages leapfrogging current thinking and psychological inertia in favor of consideration of a best possible outcome, as well as how to achieve it [10].

TRIZ publications have speculated on the observed trends in the evolutionary path followed by technology [11]. By assessing a technology's current level of maturity relative to a particular trend (such as increased dynamization within the system), it is possible to speculate on the technology's 'evolutionary potential'. Evolutionary potential represents the gap between the current believed maturity of the technology and its evolutionary limit: the point beyond which it is not considered possible for the technology to evolve.

Figure 8 demonstrates two uses of this approach. On the left, the maturity of a product is mapped relative to a series of evolutionary trends. Relative to some trends, the product is considered mature and currently utilizes state-of-the-art technology and thinking. Based on some other trends, there is room for improvement. By targeting these gaps, an organization has the opportunity to strengthen its position in the market if not other competing offerings already compete in this space.

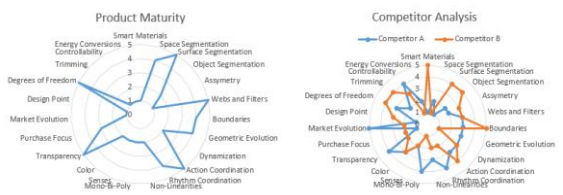


Figure 8: Evolutionary Potential Radar Plots

On the right, a comparison of competing products is shown. The variety is indicative of different technological approaches to solve the same problem. Differences in the scales favor development opportunity for market differentiation. Depending on technological viability, differences based on individual trends or groups of trends lend themselves towards the identification of new intellectual property which may be exploited by an organization. Alternatively, IP could be secured to inhibit the development of a product based on a particular technological direction.

By understanding both an organization's IP as well as that of its competitors, and directed by market trends and customer insights, technical systems evolution insights may be used to design the next iteration of products, processes, or services.

5. Portfolio Development

To increase the odds of success, companies need a healthy portfolio of opportunities to pursue. By focusing on relevant market trends, gaining insights about customer needs, and company's technology maturity, organizations can converge on a strategy for their innovation opportunities. Figure 9 shows a typical process sequence to collect and analyze these data. Market trends provide insights into the drivers of change and relevant trends applicable to the industry. Using these trends one can explore scenarios and opportunities that the organization must consider. This is then followed by a deeper understanding of the customers who are connected to these opportunities. The hypotheses developed from customer insights discussions must be validated by real data from potential customers and non-customers. Using this information a set of customer opportunities are identified and validated. One can then utilize TRIZ approach to directed evolution and trends prediction, in order to identify a healthy set of growth portfolio. The portfolio is further analyzed for attractiveness, risks and company strategy in order to prioritize them and allocate resources and investments.

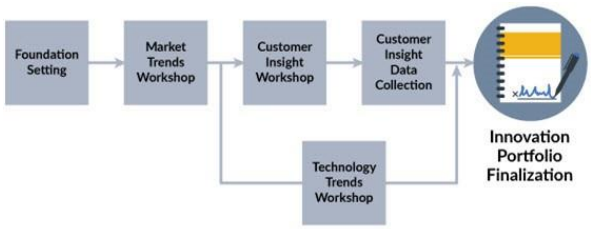


Figure 9: Portfolio Development Process

6. Summary

As creative destruction takes its toll, companies are forced to be more adaptive, innovative and agile to discover new sources of differentiation. To make the innovation process scalable, sustainable and predictable, companies must establish systematic processes and frameworks for innovation. Portfolio development is a key step in the right direction. Market trends, customer insights and technology trends are key input to this

process. While TRIZ thinking can help with market trend analysis and customer insights, TRIZ techniques and analysis form the foundation for technology trends and directed evolution. Patent analysis is used to scan the existing intellectual property in an industry. Using Sun diagram, TRIZ can be used to map the directions of technologies developed by competitors and the contradictions that are stopping them from achieving the ideal final result. Using this type of analysis, companies can develop their IP strategy. An IP landscape map also provides a high level map of intellectual property domains by key players. Finally, maturity of existing technologies is mapped with the help of TRIZ technology trends. These maps then give us clues to what opportunities to pursue. When insights from market trends, customers and technology trends are overlaid, the opportunities become clear.

References

[1] Bhide A, The origin and evolution of new businesses. New York: Oxford University Press; 2000.

[2] EU European Commission. Innovation Management and the Knowledge-Driven Economy, Directorate-General for Enterprise, ECSC-EC-EAEC, Brussels; 2004.

[3] Hargadon A., Sutton, R.I. Building an Innovation Factory, Harvard Business Review 2000; Vol. 78, 3:157-166.

[4] Hamel G. The Why, What, and How of Management Innovation. Harvard Business Review 2006; Vol. 84, 2:1-18.

[5] Csikszentmihalyi M. Flow : the psychology of optimal experience (1st ed.). New York: Harper & Row; 1990.

[6] Cavallucci D, Rousselot D. Structuring Knowledge use in inventive design, 2nd IFIP Conference on Computer Aided Innovation, Oct 8-9, 2007, Brighton, USA.

[7] Mann D., and Cole AC. Connecting Real IP Value to Business Strategy. Int. J. Systematic Innovation 2-9 (2010).

[8] Buhan, CL., and Palazzoli F, CRISPR Patent Landscape, IP Studies, July 2015.

[9] Mauborgne R., Kim WC., Blue Ocean Strategy, Harvard Business Review, 2005.

[10] Kowalick J, Psychological Inertia, TRIZ Journal, 1998 (http://www.triz-journal.com/psychological-inertia/).

[11] Mann D.L., Hands-on Systematic Innovation, CREAX Press, April 2002.

Development of creative education materials for students at middle and high school using design thinking process with simplified TRIZ

Kyeongwon LEE
Korea Polytechnic University, South Korea
E-mail: lkw@kpu.ac.kr

Abstract

This paper explains one development of education materials with TRIZ for students at middle and high schools. They use the design thinking process with simplified TRIZ. Many teachers have complained that the conventional TRIZ is very difficult to students with too much knowledge and unfamiliar words focusing mostly on mechanical inventions. In addition they want to teach the collaborative creativity and problem finding with careful observation and curiosity considering the learning knowledge of students increase year by year. Author thinks that the Design thinking process having strong points in problem finding with collaborative team play and simplified TRIZ" with interesting education samples are suitable to improve the creativity of students at middle and high school better through the twenty years' experience of TRIZ propagation in Korea.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Creative Education for Students; Design Thinking Process; Simplified TRIZ; Quick TRIZ

1. Introduction

Most countries have been very interested in promoting the creativity of students effectively.

Recently some education experts and TRIZ experts have developed TRIZ as an advanced creative education method. [1-3]

But many teachers have complained that the conventional TRIZ is very difficult to students with too much knowledge and unfamiliar words focusing mostly on mechanical inventions. [4]

In addition for students at secondary schools such as middle school (from 14 to 16 year old) and high school (from 17 to 19 year old) the collaborative creativity and team work educations are very important with much curiosity of students and the learning knowledge on public and common subjects such as Science, Technology, Engineering, Arts and Mathematics (so-called by "STEAM" education popular in U.S.A).

During one year from July, 2015 author and his colleague have developed education materials with group brainstorming and simplified TRIZ on design thinking process considering conventional knowledge educated for students at middle and high schools.

2. Methods

2.1 Design thinking process

The design thinking process with team play, problem finding by tools for empathize users and fast/ cheap prototyping step are suitable for funny collaborative creativity educations at middle and high schools. [5]

The related creativity education materials follow the design thinking process used at d.school of Stanford University basically. It uses group brainstorming as problem solving and ideation. [6]

The design thinking process first defines human-centered problem carefully and then, implements the solutions with the needs of the user demographic at the core of concept development. This process focuses on need finding, understanding, creating, thinking, and doing. At the core of this process is a bias towards action and creation: by creating

and testing something, you can continue to learn and improve upon your initial ideas.

The design thinking process consists of these 5 steps:

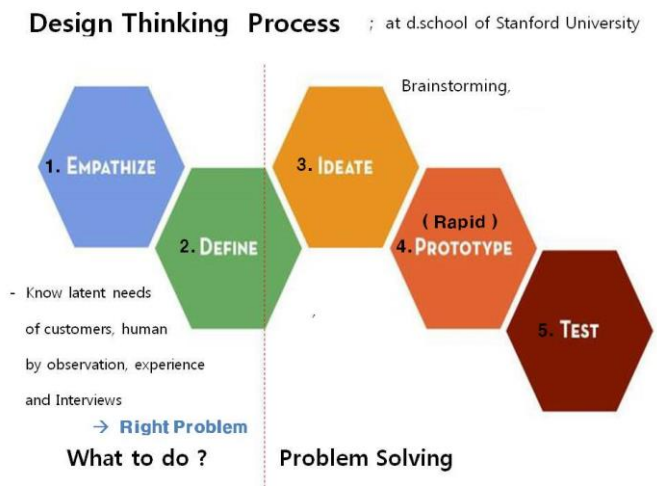


Fig.1. 5 steps of design thinking process at d.school, Stanford Univ.

1) **"Empathize" step**: Work to fully understand the experience of the user for whom you are designing. Do this through observation, interaction, and immersing yourself in their experiences
2) **"DEFINE' step:** Process and synthesize the findings from your empathy work in order to form a user point of view that you will address with your design.
3) **"IDEATE" step:** Explore a wide variety of possible solutions through generating a large quantity of diverse possible solutions, allowing you to step beyond the obvious and explore a range of ideas. In many cases, the methods to generate ideas almost depend on brainstorming of multidisciplinary team.
4) **"PROTOTYPE" step:** Transform your ideas into a physical form rapid and cheaply so that you can experience and interact with them and, in the process, learn and develop more empathy.
5) **"TEST" step:** Try out high-resolution products and use observations and feedback to refine prototypes, learn more about the user, and refine your original point of view.

The design thinking process is effective to the education for funny collaborative creativity and human-centered problem finding. But author thinks that it needs some advanced ideation-methodologies such as TRIZ more.

2.2 Compensation TRIZ on Design Thinking Process [7]

TRIZ has no steps to know human-oriented latent and changing needs. The human-centered "Empathize" step of design thinking process uses careful observation of target user's vivid actions, target user's intensive interview and solver's experience. The step knows and defines the human-centered problem correctly that target user and customer have latently.

It is much effective steps for compensating TRIZ for finding human-centered problem well as "Pre-TRIZ" stage. For nice and more implementations from ideas by TRIZ to practical innovation and commercialized products or service, the human-centered problem definition for customers can give the innovator and problem solver the inspiration to challenge. In addition, TRIZ is one method and process for just conceptual design stage. So it gives just conceptual ideas than more concrete ideas. Hence TRIZ users may not conform whether the conceptual ideas by TRIZ can be implemented by technical and business aspects in real field well or not. They need some additional steps to explain the TRIZ ideas to others. So the fast and cheap prototype step of design thinking process as "Post-TRIZ" can explain the TRIZ ideas to others more clearly.

2.3 Simplified TRIZ for young students [4]

TRIZ is suitable method to resolve the contradiction that one idea in the design thinking process generates new other problem.

However, TRIZ beginners and young students have some difficulty to model the right contradiction easily and systematically.

In addition, they have complained that the conventional TRIZ has so many tools such as 40 inventive principles, 76 standards and complex ARIZ process etc.

So many TRIZ tools with unfamiliar TRIZ words are big burden to especially, young students at middle and high school with from 14 to 19 years age, too.

Since few years ago author have devised and taught the simplified TRIZ, so-called the "Quick TRIZ" process with step-by-step conflict diagram in T.O.C (Theory of Constraints) and familiar words to general persons.

The Quick TRIZ focuses on describing the contradictions simply in systematic, visual form as shown in the Fig. 2, 3 and 4 and then, applies several frequently-used principles first.

It asks to describe the problem or the purpose of system into Box B and then, write down the first idea (as means, idea by group brainstorming in Design thinking process etc.) which can solve or satisfy the purpose of system of Box B, into Box D as shown in Fig. 2.

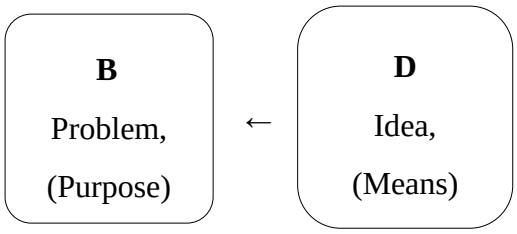


Fig.2. Pair with problem and its idea as means

The problem solver wants to remove the new other problem generated by the idea that solves the first problem in the box B.

So it asks to remove the new other problem into the box C as shown in Fig. 3 as next step.

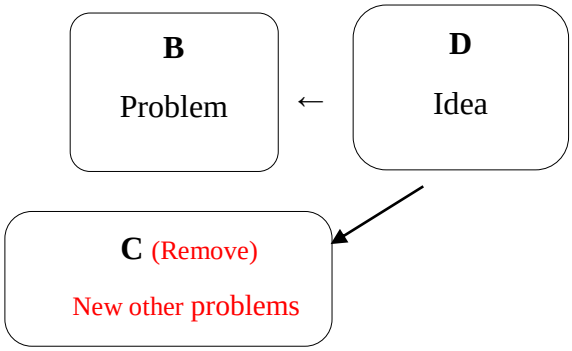


Fig. 3. Removing the new other problem by the idea to solve first problem

In Box D' shown in Fig. 4, the reverse condition corresponding to the idea to solve the first problem should be described. In other words, the minus or reverse physical condition against idea in Box D should be described in Box D'

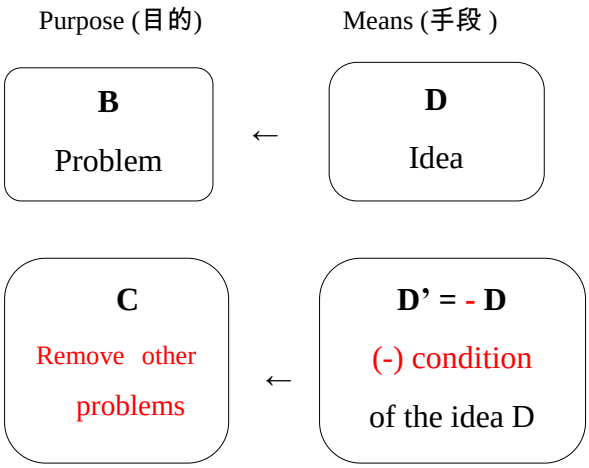


Fig. 4. Reverse condition of the idea (D') for removing the new other problem

Young students can model and see the technical contradiction in Box B and Box C and the physical contradiction in Box D and Box D' step-by-step easily and systematically.

And then, apply 4 separation principles one-by-one as frequently-used simple principles without handling many 40 principles for generating good ideas systematically as follows;

1) Generate ideas by applying "separation in time"
2) Generate ideas by applying "separation in space" including "separation in whole and parts"
3) Generate ideas by applying "separation on conditions" with difference of level, standard and condition of " if" and "otherwise"
4) Generate ideas by using other cheaper resources that author added last more to escape from fixed and existing idea, means and method.

The education and training time with modelling contradictions and applying separation principles need at most just 3 hours for young students to understand and apply it to their own problems.

Author has known that the terminology of the "contradiction" itself, specially "physical contradiction" and "technical contradiction" are what young students feel complex and difficult. So he has educated by familiar words, "the conflict between two contradictory means" instead of the physical contradiction and "the conflict between two contradictive purposes " instead of the technical contradiction.

If there is more time for educating young students, it adds just 8 inventive principles with watching the related pictographs and singing the related invention song several times together as follows [8,9];

1) Segmentation; Divide object more and more
2) Taking out; Separate only what you want
3) Local quality; Don't make the whole uniform
4) Asymmetry; Break the symmetry
5) Nesting; Place one inside the other
6) Do it in reverse; Try to invert the action
7) Dimensional Change; Change dimensional space
8) Self-service; Self-service is the best way

The number 40 of the 40 inventive principles are too many for young students to apply them well in their normal busy life.

The magic number 7 (plus or minus two) provides evidence for the capacity of short term memory. Most adults can store between 5 and 9 items in their short-term memory. This idea was put forward by Miller (1956) and he called it the magic number 7. He thought that short term memory could hold 7 (plus or minus 2 items) because it only had a certain number of "slots" in which items could be stored. In creativity field, the magic number is 7 so that normal person may handle 7 +1 [10]. Hence, the 8 inventive principles are suitable for young students and TRIZ beginners.

3. **Contents of education materials**

The education materials are composed of 3 levels for average students; basic level for 14, 15 age, intermediate level for 16 age and advanced level for high school students from 17 to 19 according to Korea's common education system as shown in Table 1.

The basic level follows the conventional design thinking process without TRIZ contents for easy and funny team-based action-learning creativity for young students at middle school. It aims at improving the ability to discover problems through natural empathy in everyday life through cooperative creative activities with group brainstorming and producing cheap and fast prototypes.

The intermediate level uses simply just 8 inventive principles and 4 separation principles of TRIZ more to resolve the contradiction on conflict diagram at the ideation step more.

The advanced level is for students at high school. It is composed of problems finding with deeper empathy and more TRIZ tools such as 9 windows.

Table 1. Composition of creativity education materials at 2ndary schools

level	age	students	ideation
basic	14, 15	1st, 2nd grade at middle school	Brainstorming, Subjects around school, home
intermediate	16	3rd grade at middle school	Quick TRIZ, Subjects on inventions with science
advanced	17~ 19	All students at high school	Advanced TRIZ, Subjects on inventions, problem solving

The self-camera stick of smart phone is most popular and interesting product in the world, especially in Korea in 2014.

As a comparative case the educational materials on the self-camera stick has been explained below in more details for each basic, intermediate and advanced levels for students at middle and high schools

3.1 Self-camera stick of smart phone for basic level for average students with 14 or 15 age [11]

In the "Empathize" step of design thinking process, he had asked to list and write down 5 complaints or things to be improved for students after using the sticks with careful observation and interviews of the stick users as following sheet by one team with 4 students as shown in Fig. 5.

On all complaints as the right problem defined, they had generated many ideas to remove the complaints by group brainstorming and brain-writing depending on their own experience, intuition and knowledge. They had shown incremental and improved ideas mostly such as using some light materials against the heavy stick in the first "heavy" complaint of problem.

Fig.5. Empathize step of self-camera stick in design thinking process

Sometimes they had not generated any useful ideas at all against other complaint as shown in Fig. 6. If there is no idea to remove the complaint, they may search for information and ideas through internet search.

Fig.6. "Ideate step" of self-camera stick in design thinking process

3.2 Self-camera stick of smart phone for intermediate level for average students with 16 age

Many times an idea may generate other new problem as the contradiction of TRIZ. For example, the needs or purpose to shoot wide-angle self-camera picture with more persons require that the distance from them to the camera position of smart phone is longer. So the length of stick is longer than that of the existing stick. The longer stick generates other new problem that users feel heavier and the stick is worse for be portable with self-deflection of the stick itself.

It requires contradictory requirements of "long" and "not long" simultaneously as the physical contradiction of TRIZ.

To fill the conflict diagram of self-camera stick in Quick TRIZ, first describe the purpose of "to shoot wide" in using the self-camera stick into the box B. Then, for instance, fill one idea, and the means of "length of stick has to be longer" into box the D by group brainstorming of the "Ideate step" of design thinking process.

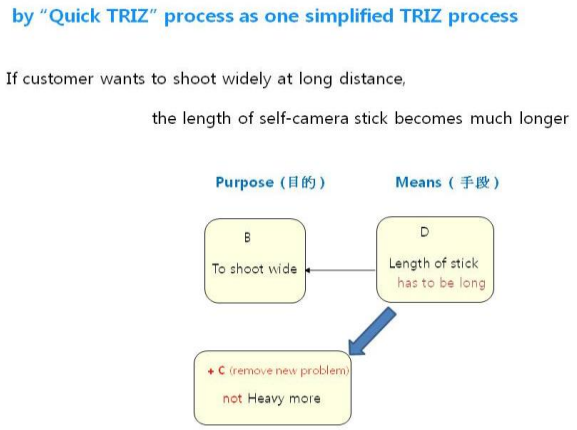


Fig.7. First step for the conflict diagram of Quick TRIZ

By the way, the longer stick generates new other problem of "heavier self-camera stick" into box C.

Solvers want to satisfy two contradictive purposes in the box B and the box C of removing the new other problem as shown in the Fig. 7.

Next solvers intentionally describe the revere means and idea of D (-D) into the box D' to satisfy the contradictive purpose by removing the new other problem as shown in the Fig. 4.

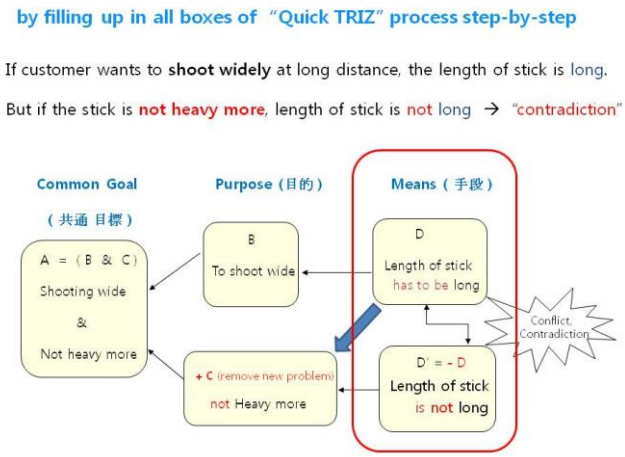


Fig.8. Conflict diagram of self-camera stick in Quick TRIZ

Thus they can model the right physical contradiction step-by-step from the idea by group brainstorming of the "Ideate" step of design thinking process.

That is, to satisfy the purpose B, "to shoot widely for taking picture with more persons by the self-camera stick", one idea and the means D is "using longer stick than existing stick". To satisfy the contradictory purpose C, "not heavy stick more", the other idea and the other means D' is "not using longer stick than existing stick". In the viewpoint of the contradiction of TRIZ, the physical contradiction of "longer" and "not longer" is modeled systematically and step-by-step as shown in Fig. 8.

To satisfy two contradictive purposes, shooting wide and not heavy more together as a technical contradiction of TRIZ, the length of stick has be longer and is not long as a physically contradiction of TRIZ.

Applying "long stick" and "not long stick" separation principles in time, space and on conditions do not generate good ideas to satisfy two contradictive purposes, "shooting wide" and "not heavy more" together.

Wide-angle lens attached to front camera of smart phone by "using other cheap resource" ideation guideline for the "long" and "not long" physical contradiction of the stick instead of mechanical antenna type stick.

The 8 inventive principles may generate other ideas. But students did not generate other ideas by them more.

3.3 Self-camera stick of smart phone for advanced level for average students with 17~19 age

In addition, solvers can use the numbered 9 windows of TRIZ more for generating new conceptual ideas of next generation self-camera sticks systematically as shown in Fig. 9. [11, 12]

Students can use the TRIZ education materials with vacant PPT templates including the simple cases to follow easily.

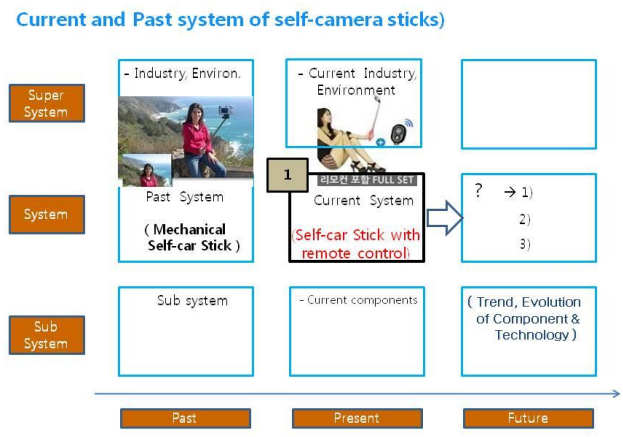


Fig.9. Numbered 9 Windows for next generation self-camera stick

First the self-camera stick with blue tooth remote control of smart phone is filled into the box, number 1 as a present system, current system in the Fig. 9.

Serially they may add all contents as the present sub system of components into the box, number 2 and then, the present super system of the environment and industry into the box, number 3, respectively as shown in Fig. 10.

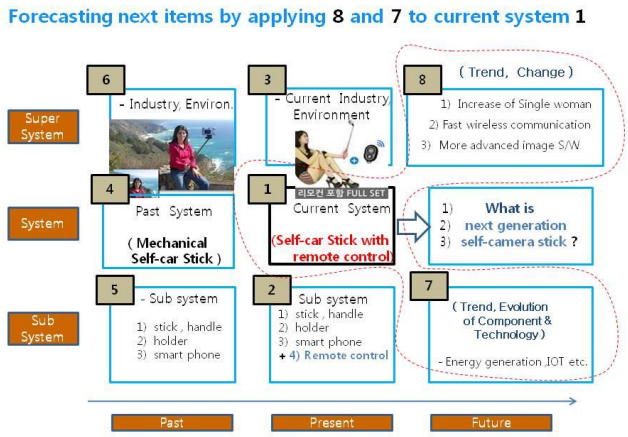


Fig.10. Numbered 9 Windows for forecasting next self-camera stick

As past system in box, number 4, the conventional and cheap mechanical self-camera stick may be selected.

After that they may add as the past sub system of components into the box, number 5 and then, the past super system of the environment and industry into the box, number 6, respectively. The present and past system with their sub system and super system are described into the numbered windows systematically step-by-step.

For forecasting the next generation of the self-camera stick in future at special time (for instance, after 2 years) they describe some components and technology considering the

trends of components and technology from past through present to the future with the immersing new technology and components into the box, number 7.

After that, they describe some trends of industry, social and customers from past through present to the future into the box, number 8, too.

All have been prepared for forecasting the future system of the next generation of the self-camera stick.

Finally they may get many interesting ideas of next generation at special time (for instance, after 2 years) self-camera stick by both applying trends and contents of the box, number 8 and applying some improved or new components and technologies- related contents in the box, number 7 to the "present current system" of the box, number 1 simultaneously.

They had generated more innovative and implementable ideas after group discussion with applying the "Quick TRIZ" process and the numbered 9 windows in short time comparing to just group brainstorming of conventional Design Thinking process as follows;

1) Self-camera stick with manually self-electric power generation by combining mechanical and manual energy generation technology in the climbing 9 windows
2) Self-camera stick with the auxiliary stick by combining increasing trends of outdoor activitie & climbing mountain in the numbered 9 windows
3) Self camera stick with the self-protection stick for young woman by combining trend of increase of single and young woman who are concerning violence seriously and latantly in the numbered 9 windows
4) Small cheap drone (as small helicopter) with cheap camera module and wireless communication concept by using other cheap resource in TRIZ with the hipe of drone popularity with removing other complaint hat users do not want to take pictures of the stick itself with unnatural posture.

4. Conclusions

The creativitity education materials for average students at secondary schools such as middle school (from 14 to 16 years old) and high school (from 17 to 19 years old) in Korea during 1 year from July in 2015 have been developed by basic, intermediate and advanced level programs with more subjects suitable to each students.

The responses from most teachers at middle and high schools who have trained by these programs and the educational materials are good.

They said that the design thinking process is much effective for creativity educations with collaborative creativity and funny action learning by team play of the students.

To promote the quality of ideas generated in design thinking process, the simplified TRIZ such as modeling contradictions easily with 4 separation principles in Quick TRIZ and then, 8 frequently-used inventive principles and then, the numbered 9 windows framework for future system considering education contents of each level students are much suitable for students comparing to the many 40 inventive principles and complex contradiction table of the conventional TRIZ etc.

Acknowledgement

This work was supported by the Korea Foundation for the Advancement of Science and Creativity (KOFAC) grant funded by the Korea government (MOE).

References

[1] Gatano Cascini et. al, TETRIS (TEAching TRIz at School) program, www.tetris-project.org, 2009.
[2] Gilles Haeffele, Carine Markgraf and David Pinaud, TRIZ education in high school and Human Resource Management for industrial competitiveness, Proceedings of 13th ETRIA TRIZ Future Conference 2013, pp. 581~588, Paris, France, October, 2013.
[3] Tatiana Sidorchuk, Nikolai Khomenko, Thoughtivity for Kids, Goal/ QPC, 2006.
[4] Kyeongwon LEE, Quick TRIZ 2012" in Korea as a simplified TRIZ Process, Proceedings of 12th ETRIA TRIZ Future Conference 2012, Lisbon, October, 2012.
[5] http://www.designthinkinginschools.org
[6] http://dschool.stanford.edu/redesigningtheater/the-design-thinking-process
[7] Kyeongwon LEE, Design thinking process with simplified TRIZ, Proceedings of 14th ETRIA TRIZ Future Conference 2014, Berlin, October, 2014.
[8] Jeongho Shin, Cheolhee Hwang and Seungmin Cha, TRIZ education using Pictographs and Music, Proceedings of 13th ETRIA TRIZ Future Conference 2013, Paris, France, October, 2013, p.769~778.
[9] https://www.youtube.com/watch?v=p1NE_L5UYrc, TRIZ Invention song (in English) in Youtube.com.
[10] http://www.simplypsychology.org/
[11] Isak BUKHMAN, TRIZ technology for innovation, Cubic Creativity Company, 2012, p.30~36.
[12] Keongwon LEE, Forecasting future of system using advanced 9 windows canvas", 5th Global TRIZ Conference 2014, Seoul, Korea, July, 2014.

Effective Design Approach with Inventive Principles to Reputational Damage Risk on the Internet

Manabu Sawaguchi[1], Satoru Utsugi[2]
[1]Waseda University, Japan; [2]NS Solutions, Japan

[1]E-mail: sawa@aoni.waseda.jp

Abstract

In recent years, we have increasingly witnessed flaming on the Internet where reputations that had spread via the Internet media brought risk to the management of companies. Such cases have been increasing every year, and concerns over reputational damage risk among companies have also been rising. Based on that background, this paper proposes a risk management method utilizing design approach to plan effective measures against reputational risk at appropriate cost levels. This methodology consists of two phases: Phase 1 to classify all risks and rationally select high risk areas, and Phase 2 to use design approach to work out measures with consideration of even unknown risks. The largest characteristics of the risk management proposed in this paper are the rational visualization of unknown risk areas with higher degrees of danger, and the design of unknown risks that cannot be found with conventional risk management methods which focus on the examination of past cases.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Design thinking; Inventive principles; Reputational damage risks; Flaming on the Internet

1. Background and objectives of the study

1.1. What is reputational damage risk on the Internet?

In recent years, we have witnessed an increasing number of incidents where reputations that had spread via social media websites caused damage to the management of companies.

Internet flaming is known as a typical phenomenon where unfavorable reputations on a company spread on the Internet, and the target company is overwhelmed with comments such as crimination, criticism, defamation, and calumniation. Internet flaming can be considered a means of creating unfavorable reputations. The number of such flaming cases has been increasing every year, raising concerns among companies on reputational risk. Yet, since companies tend to underestimate risk to themselves (lenient tendency), it is hard for them to take effective measures against reputational risk solely by themselves [1]. Under these circumstances, consulting firms which help companies reduce reputational risk are recently emerging; however, companies receiving such consultative services still face unfavorable reputations, and thus these services have not yet been sufficiently successful.

1.2. Issues involved in measures against reputational risk

A large factor that hinders the acceptance of the reputational risk consultation services by companies is the possible oversight of risk factors. This is because “learning from failure” approach advocated by Dr. Hatamura [2], which is to create a database for failure cases in the past and identify risk factors by referring to this database, is in the mainstream of the current reputational risk consultation. But since reputational risk on the Internet has rapidly increased only in recent years, the number of past cases is still limited.

Reputational risk on the Internet is a dynamic risk that changes along with social changes, such as the advancement of the net media and changes in social interests. At present, however, reputational risk consulting firms do not consider such dynamic features in planning measures, and whether or not new risks can be identified would simply depend on the abilities of individual consultants, who may also be trapped into

psychological inertia. Therefore, they should keep in mind two causes for overlooking risk factors described in the table below.

Table 1. Two causes for overlooking risk factors.

Cause	Explanation	Reason for passing over
Risk's dynamic features	Risk's characteristics caused by social and economical dynamic changes	Past inspection thinking doesn't consider dynamic changes
psychological inertia	The phenomenon of narrow scope thinking based on one's own knowledge and past experience	Past inspection thinking make narrow scope thinking

1.3. Introduction of design approach

As discussed in the previous section, the method of analyzing past cases alone cannot deal with new risks, and thus a future-oriented method is required to predict them. This study makes an attempt to use the reverse thinking approach in sabotage analysis [3]. This approach predicts risk factors by asking a question about how to cause a failure, instead of a question about why a failure has occurred. It is a design approach that utilizes creativity to make risks apparent. The authors have named this approach Creative Risk Management Approach based on Reverse Thinking (CRMART), and have verified its effectiveness in projects such as ICT (information and communication technology)-Based Risk(s) [4], and Backup System (BUS) of the Expressway Traffic Control System for Metropolitan Expressway Company in Japan [5]. This paper presents a procedure for planning measures against reputational risk on the Internet (see Fig. 4), which has been specifically developed for professional consultants specialized in reputation risk reduction, and which also draws on the strengths of the CRMART design approach. According to Boyd D, et al. [6], common patterns are shared by all inventive solutions, and it is effective to think within limitations based on patterns to generate creative ideas without relying on existing knowledge. Based on this idea, this study uses inventive principles advocated by Altshuller in an attempt to break psychological inertia and predict unknown risks.

2. Scope of the study and characteristics of the proposed methodology

2.1. Scope of the study

The figure below describes a process for planning measures against reputational risk on the Internet conducted by Company E, a consulting company in this field. The process is divided into three stages: planning measures, implementation and evaluation, and this study focuses on planning measures. This stage consists of four steps: 1. Risk categorization to narrow down risks, 2. Risk evaluation, 3. Identification of risk factors (causes), and 4. Planning of proposed measures. This study covers all these four steps (see Fig.1).

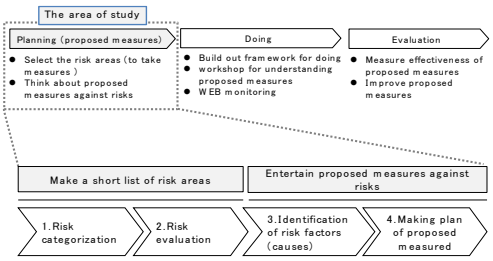


Fig.1. A process to draw up measures against reputational risks on the Internet

2.2. Characteristics of the proposed methodology in comparison with the current methodology

Fig. 2 compares the current methodology and that proposed in this paper for each of the four steps shown in Fig. 1.

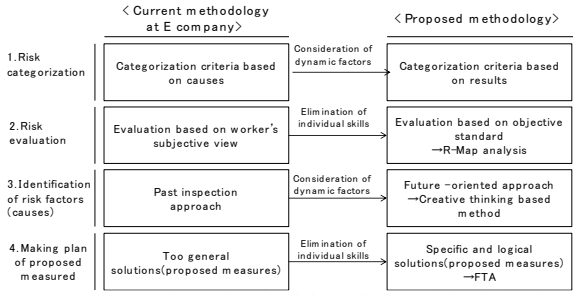


Fig. 2. Comparison of methodology characteristics in the four steps

The proposed methodology introduces R-Map analysis (to be discussed later) in "2. Risk evaluation" to eliminate differences in individual skills. This characteristic allows for the objective selection of risks. The second characteristic is the introduction of creative thinking based on TRIZ inventive principles to "3. Identification of risk factors (causes)". This approach offers efficient responses to the dynamic characteristics of reputational risk. Then, the third characteristic is the combination of creative thinking and FTA (fault tree analysis) (to be discussed later) in "4. Planning of proposed measures" to predict all risk factors and logically establish relations between the predicted risk factors, thereby making it highly possible to select minimum required measures. The next chapter will briefly discuss the characteristics of each step for the process to draw up measures against reputational risk on the Internet (see Fig. 3).

3. Proposals

3.1. Overview of the process to draw up measures against reputational risk on the Internet

A process for planning measures should involve two phases: the first phase to classify all risks and rationally narrow down risk areas, and the second phase to predict all risks including unknown ones and work out measures. Therefore, in this study also, there are phase 1 for selecting risk areas and phase 2 for working out measures (see Fig. 3).

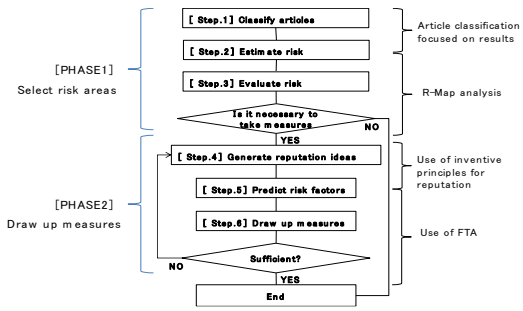


Fig. 3. A procedure to draw up measures against reputational damage risk on the Internet

3.2. ［PHASE 1］ Select risk areas

3.2.1. Article classification focused on results

The purpose of phase 1 is to objectively and efficiently select areas with high risk. To do this, certain criteria should be set to classify hazard information which is the source of risk. Conventional criteria for classification focus on causes of flaming on the Internet, such as "confession of antisocial behaviors" and "defamation and contempt to a specific target"; however, these criteria may not cover all causes because there are too many causes. This paper proposes a classification method by stakeholders which focuses on the results of flaming on the Internet. Robert G. Eccles said, "a company's overall reputation is a function of its reputation among its various stakeholders." [7] It suggests that classification by influence on stakeholders should be able to classify all information related to creating overall reputation for a company.

[Step 1] Classify articles

Stakeholders who have common subjects of interest were grouped and classified into three categories based on the type of relations: investment, employee, and trade relations. A category of "other" was added, which may include exceptions. Then, articles on a list of hazard articles (241 cases) collected by a joint research partner were classified into these four categories to confirm the availability of the four categories.

Table 2. Relation categories

Reputation type	Assumed objects	Common topics	Examples of hazard
Investment	Shareholder, Financer	Equity price, Yieldability	Law Violation, Information leak
Employee	Job applicant, Employee	Recruitment, Employment reality	Workplace inequality
Trade relations	Customer, Business acquaintance	Commercial goods &service	Complaint, Criticism against sales promotion
Other	NPO, Other	Social liability, Other	Behave at variance with public order and morality

3.2.2.R-Map analysis

R-map analysis is used to estimate and evaluate risk by relation category. This method uses a matrix for the event probability and degree of danger to show the scale of risk (see Fig. 5). It is used as a risk evaluation tool for product accidents by the Ministry of Economy, Trade and Industry [8].

[Step 2] Estimate risk

To estimate the event probability, the ratio of negative articles to all articles in each relation category is used. Its relative scale is calculated as event probability deviation, based on which rating is given on a scale of five (see Table 3).

Supposing that *i*-th media is $M_i(1 \le i \le I)$, *j*-th relation category is $R_j(1 \le j \le J)$, the total number of articles is N, and the total number of negative articles is H, the ratio of negative articles to all, P, can be expressed with the following formula:

$$\mathrm{P} = \frac{H}{N} \qquad (1)$$

In *j*-th relation category for *i*-th media, supposing that the total number of articles is n_{ij}, and the number of negative articles is h_{ij}, the ratio of negative articles to all, P_{ij} , can be expressed with the following formula:

$$P_{ij} = \frac{h_{ij}}{n_{ij}} \qquad (2)$$

From (1) and (2), the standard deviation, σ, for the ratio of negative articles can be expressed with the following formula:

$$\sigma = \sqrt{\frac{1}{I \square J}\sum_{i=1}^{I}\sum_{j=1}^{J}\left(P_{ij} - P\right)^2} \qquad (3)$$

From (1), (2), and (3), the event probability deviation in the *j*-th relation category for the *i*-th media, T_{ij} , can be expressed with the following formula:

$$T_{ij} = \frac{10\left(P_{ij} - P\right)}{\sigma} + 50 \qquad (4)$$

Table 3. Event probability estimation table

Deviation of event probability	Event probability	Event Possibility about rumor(s)
$70 \le T_{ij}$	5	It could being occurred already
$60 \le T_{ij} < 70$	4	It can be triggered off by almost anything
$50 \le T_{ij} < 60$	3	It can highly be triggered off
$40 \le T_{ij} < 50$	2	It can be triggered off
$0 < T_{ij} < 40$	1	It can hardly be triggered off

Meanwhile, to estimate the degree of danger , rating is given to the danger of the highest degree in each relation category on a scale of five. Criteria for the rating were created with reference to the list of hazard articles (241 cases) mentioned earlier.

Table 4. Danger degree estimation table

Maximum dangerous extent	Dangerous extent	Damage scale regarding the occurrence of harmful rumor(s)
D = 5	5	High possibility of endangered damages
D = 4	4	High possibility of serious damages
D = 3	3	High possibility of damages
D = 2	2	Possibility of damages
D = 1	1	Low possibility of damages

[Step 3] Evaluate risk

When the sum of the event probability and degree of danger exceeds a threshold, measures should be taken. The threshold is different depending on the intent of client companies, but as a guide, the authors determined that risk cannot be tolerated when the sum is 8 or higher, that risk reduction is recommended when the sum is 6 or higher and below 8, and for below 6, there is no danger (see Fig. 5).

3.3. ［PHASE 2］ Draw up measures

3.3.1. Handling of the dynamic characteristics of reputational risk

As mentioned in Chapter 1, PHASE 2 uses a design approach, or creative thinking, to predict risks, without simply relying on past cases. To draw up measures, ideas should be first generated from a viewpoint of how to create reputations from hazard information (Step 4). Then, using those ideas as top events, risk factors are identified from a viewpoint of how to worsen top events (Step 5). These steps enable us to predict risk factors creatively without limiting our thinking to past cases and our experiences.

3.3.2. Use of inventive principles for reputation

[Step 4] Generate reputation ideas

This step is intended to reduce the possibility of looking over serious risks, which means to break psychological inertia in idea generation and strengthen imagination and creativity. As a tool to support idea generation, inventive principles are used. Inventive principles are often used in combination with

contradiction matrix, and are the most frequently used TRIZ tool to support idea generation. In this study, however, out of 40 inventive principles, only those useful for generating reputation ideas were selected by reference to Matrix 2003 developed by Darrell Mann, et al. [9] and "inventive principles that should always be considered" obtained from their research. Reputation is created by exaggerating or overinterpreting the source information. On the other hand, on the Internet where numerous rumors or disinformation swirl around, incredible information is neglected and thus disappears. This means that there is a contradiction in reputation that we want to exaggerate information but exaggeration would reduce its credibility. Therefore, inventive principles useful for solving this contradiction should be selected. First, how to select useful inventive principles for exaggerating or overinterpreting the source information is explained below. In Matrix 2003, "amount of information" was selected as the parameter to be improved, and "reliability" was selected as the parameter that worsens to extract appropriate inventive principles. Then, from the list of "inventive principles that should always be considered," "amount of information" was selected to extract appropriate principles (see Fig. 4).

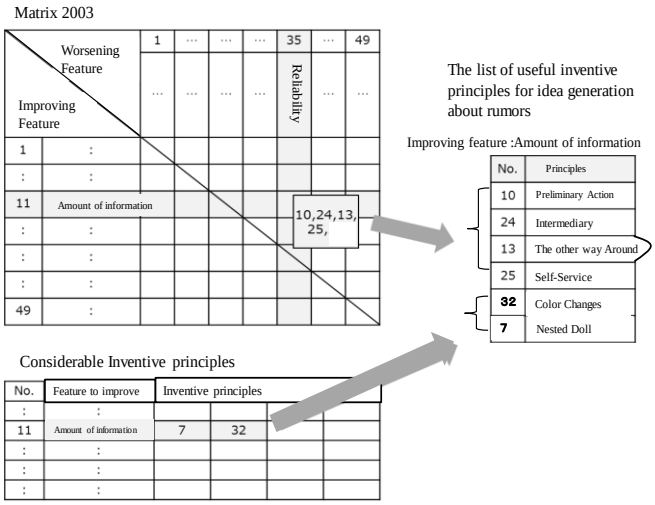


Fig.4. Extraction process of useful inventive principles

Inventive principles to ensure reliability were then extracted with the same process after the said parameters were arranged with the row and column of Matrix 2003 reversed. Table 5 shows inventive principles extracted from the both parameters. If principles (10, 24 and 32) related to the both parameters were counted as one, a total of 10 principles were extracted for reputation.

Table 5. Inventive principles for reputation

Improving feature : Amount of information

No.	Name of principle	Explanation
10	Preliminary action	Introduce a useful action into an object or system (either fully or partially) before it is needed.
24	Intermediary	Introduce an intermediary,which can be easily removed after it has completed its function, between two actions.
13	The other way around	Use an opposite action(s) used to solve the problem. Make movable objects fixed, and fixed objects movable.
25	Self-service	Enable an object to perform functions itself. Make use of waste substances or energy
7	Nested doll	Allow one object to pass through an appropriate hole in another
32	Color changes	Change an invisible object ,process , its color and its transparency

Improving feature : Reliability/Robustness

No.	Name of principle	Explanation
10	Preliminary action	Introduce a useful action into an object or system (either fully or partially) before it is needed.
24	Intermediary	Introduce an intermediary,which can be easily removed after it has completed its function, between two actions.
32	Color changes	Change an invisible object ,process , its color and its transparency
3	Local quality	Enable objects to carry out different useful functions
5	Merging	Physically join or merge identical or related objects, operation or functions.
28	Mechanics substitution	Replace an existing means with a means making use of another sense.
35	Parameter changes	Change an object's state

3.3.3. Use of FTA (Fault Tree Analysis)

For risk factor prediction and planning of measures, FTA is used. FTA is a top down approach to prevent an undesired event, or a top event, from occurring by identifying the potential causes of that event.

[Step 5] Predict risk factors

Reputation ideas are set as top events, and the primary and secondary risk factors that worsen the events are predicted using reverse thinking. Causal relations between the risk factors are shown with logic symbols ("OR" and "AND" gates). The causes at the lowest level thus predicted are considered to be subjects for which measures should be taken. [Step 6] Draw up measures

a) List proposed measures

From reputation ideas in the fault tree diagram, events at the lowest level are regarded as the ultimate risk factors, for each of which, measures to control, detect or reduce should be planned (see Table 6).

Table 6. Types of measures against reputation risk

Countermeasure	Explanation	Examples
Determent	Preventive measures against occurrence of risk factors	Build out risk management structure Literacy training course for employees
Screening and detection	Early detection of risk factors and prompt action	Monitoring on the net Investigation of SNS
Reduction	Minimize the damage from spreading after occurrence of risks	Prepare the manual of emergency response

If major areas (locations and persons) for the risk factors to arise are indicated, the scope to be covered by measures can be defined.

b) Select measures

Only necessary measures should be selected in consideration of connection between the risk factors. All factors which are connected with "OR" gates require measures. For factors connected with "AND" gates, those for which measures can be more effective should be selected, and measures are then selected. The processes leading up to this stage should be shown to experts in Company E, and when they say that the measures are sufficient, the procedure may be terminated.

4. Verification of the methodology using an example case

4.1. Set the situation

To verify the effectiveness of this approach, comparison was made between the consulting company E's conventional method and that proposed in this study to plan measures.

Two experienced employees with the same skill level were

chosen. One used the conventional method, and the other used the proposed method to draw up measures against reputational risk on the Internet for Company A, which is a client for Company E. In the implementation of the proposed method, spreadsheets were created by Excel to help these employees reproduce the procedure accurately.

Table 7. Attributes of the two employees

Basic attribute	An employee utilizing conventional approach	An employee utilizing proposed approach
Age	20's	20's
Service years	1 to 2 years	1 to 2 years
A hiring pattern	Part-time employment	Part-time employment
E experience of the Business(Reputational risk management)	Posses	Posses

In selecting two employees, consideration was given to minimize the influence of differences in individual abilities. Two young employees having the same ability level and work experience were selected. In the later stage, more experienced employees were asked to evaluate the results of these young employees.

4.2. Implementation of the proposed methodology

4.2.1. [Phase 1] Select risk area

[Step 1] Classify articles

Articles on Company A (a total of 224 articles) which had been posted on the net media (Twitter, boards, blogs, buzz marketing sites, and net news) were collected for one month, and classified by relation category (see Table 8), and the ratio of negative articles in each category for each type of media were calculated (see Table 9).

Table 8. Spreadsheet for article classification (partial)

Text	Media	Reputation type	Judgment	Dangerous extent
**********	Twitter	Financial interest	Neutral	-
**********	Bulletin board	Labor relation	Negative	3
**********	Bulletin board	Business connection	Neutral	-
*********	Twitter	Labor relation	Negative	1
**********	-	-	-	-

Table 9. Ratio of negative articles in each category (partial)

Media $M_i(1 \le i \le 5)$	Type $R_j(1 \le j \le 4)$	neutral	Negative h_{ij}	Total of articles n_{ij}	Negative ratio P_{ij}
Twitter	Investment	4	1	5	20%
Twitter	Employee	19	0	19	0%
Twitter	Trade relations	11	1	12	8%
Twitter	Other	1	0	1	0%
Board	Investment	4	0	4	0%
Board	Employee	1	4	5	80%
Board	Trade relations	2	0	2	0%
		0	0	0	0%

[Step 2] Estimate risk

The event probability deviation, T_{ij} , was calculated to determine the event probability, and degree of danger was determined according the danger degree table (see Table 4) to estimate risk.

Table 10. Risk estimation results (partial)

Media $M_i(1 \le i \le 5)$	Type $R_j(1 \le j \le 4)$	Negative ratio P_{ij}	Event probability deviation score $_{ij}$	Incidence ratio	Dangerous extent
Twitter	Investment	20%	56	3	2
Twitter	Employee	0%	45	–	–
Twitter	Trade relations	8%	50	2	3
Twitter	Other	0%	45	–	–
Board	Investment	0%	45	–	–
Board	Employee	80%	89	5	3
Board	Trade relations	0%	45	–	–

[Step 3] Evaluate risk

The results of risk estimation determined in step 2 were plotted on the R-Map. On the R-Map, the risk becomes higher toward the upper right (in darker color). For this example, the authors determined that "message boards/employee relation" requires measures (see Fig. 5), and carried out PHASE 2.

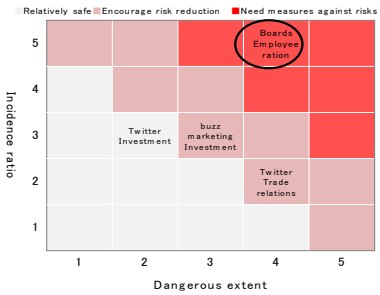


Fig.5.Extraction process of useful inventive principles

4.2.2. [Phase 2] Draw up measures

[Step 4] Generate reputation ideas

Stakeholders with high degree of danger to the company were selected, and an undesirable decision for the company was set as the top event. In this example, "persons who wish to move to Company A" were the stakeholders, and "Decision not to move to Company A" was the top event (in actual cases, more than one item is often selected).

Based on a prediction that "possibility of being a 'black' company" is a major factor in deciding on whether or not to move to that company, idea generation was carried out for "giving certainty that it is a 'black' company (primary factor)." Specifically, ideas were generated based on two negative articles: "verbal and physical abuse" and "sexual harassment to female employees." These articles were sufficient in nature to create reputational damage, but since they were posted on anonymous message boards, they lacked reliability. Therefore, "reliability" was set as the parameter to be improved. In this case, reliability of the article should be raised but posting facts alone would reduce its impact. Ideas to solve this contradiction were generated using the inventive principles (see Table 11).

Table 11. Generated ideas (partial)

No.	Principle	Idea
10	Preliminary action	Utilize similar information someone already wrote on the net(similar article)
24	Intermediary	Record the coverage through telephone interview to the relevant department
5	Merging	Combine past posting with new posting to make the reason of unimproved situation (existed information)(new information)

[Step 5] Predict risk factors

The top event was a "decision not to move to Company A," and the primary factor was "giving certainty that it is a 'black' company." Generated ideas were used as candidates for secondary factors or below. Considering the logic of "OR" and "AND," the fault tree diagram was deployed further down to the fourth factors. As a result, nine low-level events (shown within the thick frames in the figure) were predicted. In this example, they were the third or fourth factors.

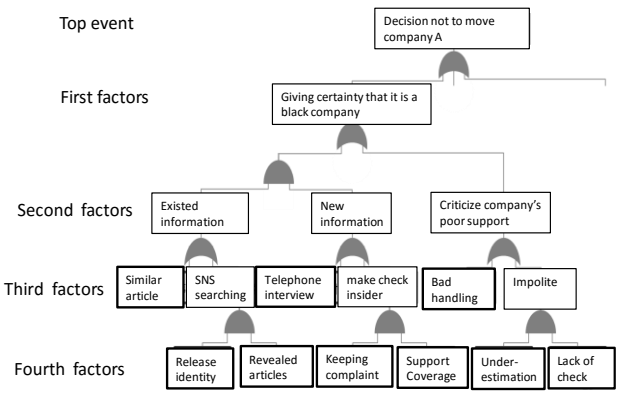


Fig.6. FT diagram to predict risk factors that could invite 'black' company reputation

[Step 6] Draw up measures

For each of these nine risk factors, measures to control, detect, or reduce risk were planned.

Table 12. List of proposed measures

Risk Factors	Place	Control	Detect	Reduction
Hitchhiked article	Twitter,2ch		Monitoring Internet	
Release identity	Twitter, blog	Onboarding	Check on SNS	Give a reaction for individual
Revealed Article	Twitter, blog	Onboarding	Check on SNS	Give a reaction for individual
Telephone Interview	Contact to give a reaction	Training course for contact personnel	Monitoring Internet	
Keeping complaint	Insider	Improvement of employment environment	Survey	
Support Coverage	Insider	Onboarding	Survey	
Bad handling	Spokesperson	Training course for contact personnel	Monitoring Internet	Emergency response
Underestimation	Spokesperson	outsourcing	Monitoring Internet	Emergency response
Lack of check	Spokesperson	Build framework	Monitoring Internet	Emergency response

From these measures, only necessary ones should be selected based on connection between the risk factors. All factors which were connected with "OR" gates required measures. For factors connected with "AND" gates, those for which measures can be more effective were selected, and measures were then selected.

5. Verification of the results

5.1. Comparison of the results

To evaluate the effectiveness of the proposed methodology, comparison was made with the conventional methodology. In terms of the time taken, cost and variety of measures, numerical comparison (based on numerical values against 100 for the conventional method) was made, while the level of satisfaction on the measures was also evaluated based the questionnaire for experienced employees.

Table 13. Comparison table with the conventional methodology

	Current method	Proposed method
※ Time taken	100	133
※Cost	100	80
※Variety of measures	100	167
Level of satisfaction	Low	High

※Numerical comparison based on numerical values against 100 for the conventional method

5.2. Discussion

The time spent for the proposed methodology was about 1.3 times longer than the conventional one. This is because [Step 4] and [Step 5] needed time due to additional work of idea generation, which is not included in the conventional method. Meanwhile, the cost was 20% lower than the conventional one because the media monitored and the number of employees trained were limited. The variety of measures increased by 67%from that with the conventional one. This was probably because measures which had not been noticed with the conventional methodology were identified with the proposed method.

For level of satisfaction, the results of the questionnaire to experienced employees showed higher satisfaction for the proposed method because they said "the process leading to the proposal of measures is clearly defined and the necessity of the measures is apparent". From these results, although time increase should be addressed in the future, the proposed methodology has achieved the objective of planning measures necessary and sufficient to reduce reputational risk.

6. Conclusion

Reputational risk consultants at companies such as Company E usually extract risk factors from a huge amount of information posted on the Internet media, classify, evaluate and predict risks based on the cases and experiences in the past, and then plan measures. But this is a new business sector and has only a limited number of experienced consultants. Therefore, inexperienced young consultants often play a major role in planning measures. They may not be able to classify risks completely, or may overlook unknown risks. At the same time, since research on the risk management of reputational damage on the Internet has not yet been conducted extensively, procedures and processes depend on individual consultants and practices are not shared. Therefore, in this paper, the authors organized information related to reputational risk management and created a procedure for some part of the work process to show that the risk management work can be visualized. This paper shows that conversion of tacit knowledge to organizational knowledge can help companies reduce their reputational damage risk on the Internet.

References

[1]UeharaH.The Existence of the 'Third Risk' in Operational Risk,Journal of Japan Assciation for Management Systems, Vol.18 No.1, 2003, pp.65-71.

[2]Hatamura,Y. Learning from Failure, SYDROSE LP, 2002

[3]Kaplan,S., Visnepolsci,S., Zlotin,B. and Zusman,A. New Tools and Risk Analysis, Ideation International Inc,1999

[4] Sawaguchi, M. Research on the Efficacy of Creative Risk Management Approach based on Thinking, Procedia Engineering 131, 2015, pp.577-589.

[5]Sawaguchi,M. and Itaru N. Verification of Risk Countermeasures Regarding Expressway Traffic Control System Based on Creative Risk management Approach, Proceedings of PICMET, 2014, pp.89-98.

[6] Boyd D. and Jacob G.,Inside the box, Simon &Schuster, 2013

[7] Eccles G.R., Reputation and its Risks, Harvard Business Review, 2007

[8]Sakai,K. Risk comparison between electrical home appliances, and other products. : The application of the R-Map method, and FTA method, The Technical Report of The Proceeding of The Institute of Electronics, Information and communication Engineers, 2011, 111.371., pp.13-16.

[9] Mann D., Simon D., Boris Z.and Alla Z., Matrix 2003, CREAX Press, 2003

Enhancing Patent Portfolio Using TRIZ Workshops

Zeihsel, Frank[a]*; Thurnes, Christian M.[b]; Schulze, Jan[c]

Synnovating GmbH, Mozartstr. 25, 67655 Kaiserslautern, Germany
University of Applied Sciences Kaiserslautern, OPINNOMETH, Amerika Str. 1,66482 Zweibrücken, Germany
thyssenkrupp Intellectual Property GmbH, ThyssenKrupp Allee 1, 45143 Essen, Germany

* Corresponding author. Tel.: +49 631 205 7784 43; fax: +49 631 205 7784 19. *E-mail address:* zeihsel@synnovating.com

Abstract

This article will show on an industrial case how TRIZ is used to strengthen and enhance the patent portfolio of companies. Therefor a special workshop setting is created. Resulting from typical boundaries within companies the preparation as well as the execution of the workshops that can be divided into problem solving and patent enhancement sections are described in this article. In addition a summary of the workshop results is presented.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: TRIZ; Patent Enhancement; Patent Portfolio; ITRIZ

1. Introduction

Patents are today the main currency of technology companies as well in the national as in the international competition. To enable the engineers to think about new technical solutions which could then be patented, the TRIZ approach was clearly suited best by thyssenkrupp, since it combines a structured process (usually favored by technically versed people) with a creativity stimulating setting.

There was a demand by thyssenkrupp to work on the enhancement of the patent portfolio in one-day workshop sessions to spare the resources of the involved subject matter experts. With that every workshop can be considered as a small project, since the variety of topics within a multi-national company always requires an induction for the workshop facilitator.

2. Workshop for enhancing the patent portfolio

Once the business areas for enhancing the patent portfolio of the company are defined, it is necessary to find out if there is a specific problem or need the workshop can deal with which then can be used as a starting point for creating ideas for new patents.

With the problem identified the workshops have to be planned properly. For this a standardized procedure has been set up to give the departments a clear outline what to do. First element is a timeline that has to be followed to assure a successful workshop.

2.1. Workshop timeline

Beside the one day for the workshop itself the timeline for the preparation and post-workshop work spans from two to two and a half weeks. Figure 1 gives an overview of the intended timeline.

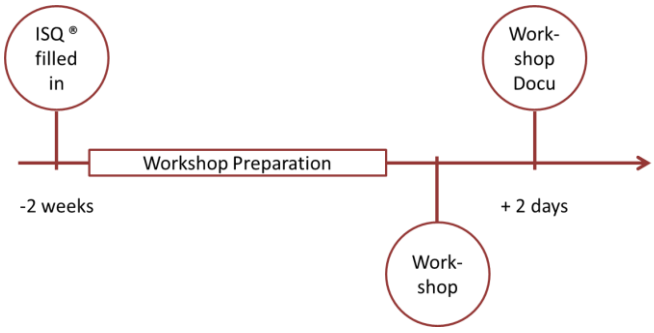


Figure 1: Workshop timeline

The main elements of this timeline are:

- Two weeks before the workshop a filled in Innovation Situation Questionnaire (ISQ®)
- The Workshop Preparation phase
- The Workshop itself
- The Documentation of the workshop

The single elements will be described more closely in the following.

2.2. Filled in ISQ®

The filled in Innovation Situation Questionnaire (ISQ®) fulfills two functions within this workshop scope.

- First, it enables the workshop facilitator to understand the area of the problem and to prepare the workshop
- Second, it is used as a tool later on in the workshop to get all participants to the same level of understanding.

The ISQ® is filled by team members that will also attend the workshop later on. The structure of the ISQ® can be seen in detail at [1]. The ISQ is used to collect and structure the information about the problem situation as there are mainly:

- System name, structure, and function
- Information about the problem and the problem mechanism
- System history
- System inputs and outputs
- Allowed changes
- Available Resources

The ISQ® is transmitted to the workshop facilitator who uses it for the preparation of the workshop.

2.3. Workshop Preparation

With the ISQ® as basic information the workshop facilitator starts the preparation. First an additional information gathering takes places using articles, publications, web searches related to the system as well as a brief search and analysis of patents regarding the considered topic, especially finding more detailed information about the problem mechanism.

Next, with a deeper understanding of the system the facilitator creates a model of the system and the problem situation. Therefore we use the Problem Formulator contained in the Innovation Workbench (IWB®; TRIZSoft® of Ideation International Inc.). In the Problem Formulator a network of cause-and-effects of related functions and events is built. The Problem Formulator provides the so called "Directions for Innovation", problem statements derived from the created model [2]. Figure 2 shows an example of a completed modelling by Problem Formulation.

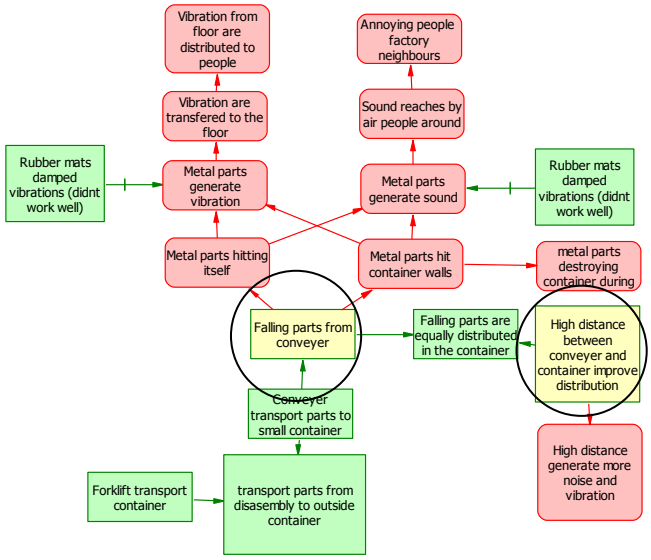


Figure 2: Problem Formulator Model

The Problem formulator shows the useful functions (green rectangle), the harmful functions (red rectangle with rounded corners), and contradictions marked with circle, characterized in that, that a useful function is prerequisite for another useful function and causes at the same time a harmful function.

Formulated Directions for Innovation are for example:

- Resolve the contradiction: *Falling parts* from conveyor should be provided to produce *Falling parts are equally distributed in the container* and shouldn't be provided to avoid *Metal parts hitting itself* and *Metal parts hit container walls*. (Example for contradiction)
- Find a way to eliminate, reduce, or prevent *Metal parts generate vibration* in order to avoid *Vibration are transferred to the floor* under the conditions of *Metal parts hitting itself* and *Metal parts hit container walls*. (Example for harmful function)
- Find an alternative way to obtain *Conveyor transports parts to small container* that provides or enhances *transport parts from disassembly to outside container* and *Falling parts from conveyer*.

With the preparation of the model and the list of "Directions for Innovation", the preparation of the workshop is done.

2.4. Workshop

The workshop itself is the core of the idea generation phase for new patent ideas. Therefore it follows the structure shown in Figure 3.

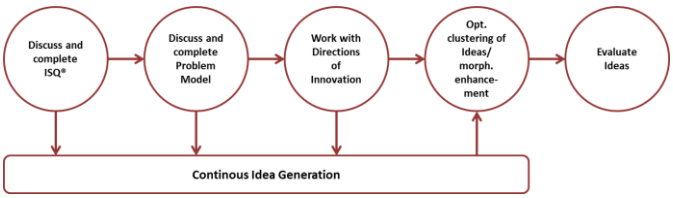


Figure 3: Workshop structure

2.4.1. Workshop setting

The workshop takes place on a single day (approx. 8-9 hours). The team involved should not exeed 10 persons including the facilitator. Best is five to six subject matter experts (people open minded for innovation from other departments or business units are also welcome) and one or two members of the patent department (patent engineer or patent attorney).

2.4.2. Workshop structure

As mentioned above the workshop follows a given structure to ensure that all necessary steps are processed.

2.4.2.1. Continuous Idea Generation

Goal of the workshop is to create as many ideas as possible for new patents. To support this, the participants are requested to document their ideas immediately by writing them on a big post-it or similar, present it to the other participants by reading it loud and explaining it, and put it to the so called "Idea Pool", a brown paper board placed in the room so everyone can see the ideas. Furthermore the facilitator documents every idea in a software tool.

So in every step of the workshop, ideas are created and collected in the idea pool. Advantage of putting them on a board is that they are permanently visible and may be inspiration for further ideas.

2.4.2.2. Discuss and complete ISQ®

Besides being a basis for the facilitator for preparing the workshop the ISQ® is also used as a tool to bring all workshop participants to the same level of understanding. This is done by discussing the content of the ISQ® to the participants and discussing those items with them. Remarks and annotations are documented in the ISQ® for the later documentation of the whole process.

Patent ideas generated during this step go to the Idea Pool. As the experience of many conducted workshops shows: even in the phase of discussing obviously known things (as system structure, system functioning, problems and problem mechanisms) a big number of ideas arise by following the questions of the Innovation Situation Questionnaire.

2.4.2.3. Present and complete Model

The cause-and-effect model documented in the Problem Formulation is presented to the participants of the workshop. The relations between the boxes are discussed and changes due to the group decision are made. Also additional items may be added as they result from changes or additions made at the ISQ® in the step before.

Sometimes no changes to the model are necessary, which means that the facilitator has done a good job preparing the model and the team has won a common understanding of the system.

2.4.2.4. Working with the Directions for Innovation

The Directions for Innovation are derived from the Problem Formulator Model. Should changes to the model have been necessary in the step before, the list of the Directions for Innovation is adjusted and the new Directions are added to the existing list.

Working with the Directions for Innovation can be divided into three tasks, sorted by relevance:

- Solving Contradictions
- Eliminating Harmful Functions
- Improving Useful Functions

The biggest potential for (patent) ideas is based on the solution of contradictions, followed by elimination or prevention of harmful functions or effects in the system. Last but not least is the improvement of the useful, intended functions. There is a certain potential for new patent ideas as one may find completely new approaches by changing the working principle for example, but those ideas have shown that they will need a big effort to prove for a patent that they will work.

To address the three tasks for working with the Directions for Innovation, the IWB® (Ideation Inc.) is used. There, for each Direction a set of operators (principles, effects, etc.) as well as analogies and examples are presented to stimulate the idea generation. For solving the contradictions we regularly use the separation principles as shown in Figure 4. Thereby each separation principle is staffed with many operators to create innovative solutions. The system of operators contains operators out of several classical TRIZ tools (like the standard solutions and the inventive principles) as well as operators developed by TRIZ masters like e.g. Boris Zlotin and Alla Zusman [1].

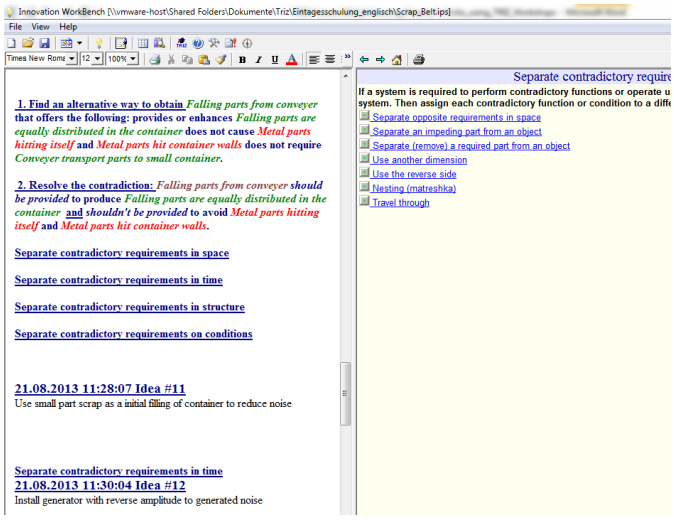


Figure 4: Using separation principles and detailed operators for solving contradiction (here: separation in space)

As well harmful functions are also reduced, prevented or eliminated using the Directions in the IWB (see Figure 5)

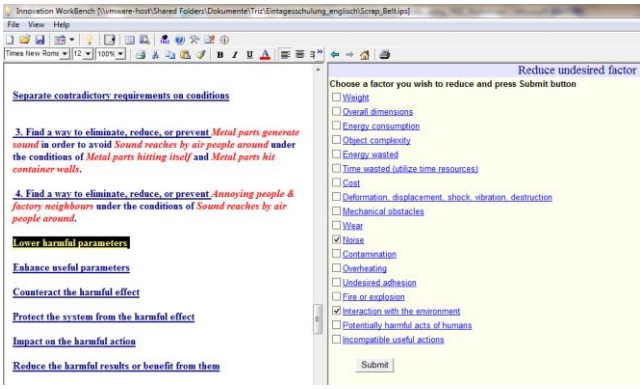


Figure 5: Working with harmful functions

2.4.2.5. Optional: Clustering and morphological enhancement

Depending on the numbers of ideas generated it might be necessary to cluster the ideas to groups using an Affinity Diagram or similar [2] (see Figure 6). Therefor related ideas are put together in a cluster and the cluster is labeled with an appropriate name.

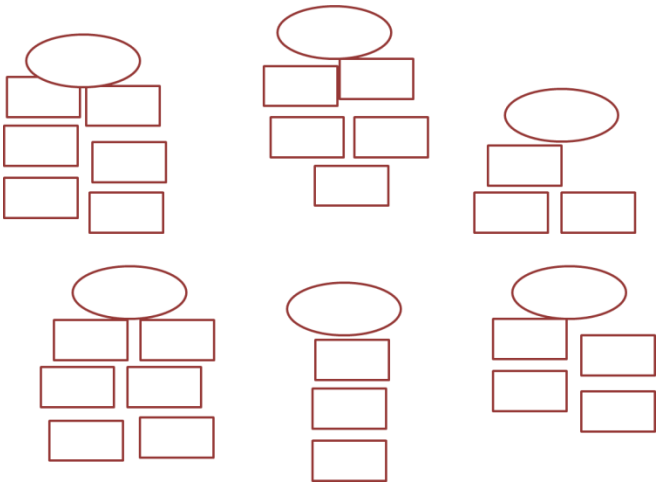


Figure 6: Clustering ideas with an Affinity Diagram

After that the clustered ideas might go to a morphological scheme, where the cluster names are put into the first column and the related ideas go to the row connected to that group name.

Different solution concepts are then created by connecting the ideas from each row (see Figure 7).

2.4.2.6. Evaluation of ideas

The last step of the workshop is the evaluation of the ideas. There again are different ways to take: for example one can use the Analytical Hierarchy Process (AHP) according to Thomas L. Saaty [3] to rate the concepts generated with the morphological box against a number of criteria. Alternatively one can use a more simple process like the point rating system to create a ranking amongst the concepts.

If you skipped the step of clustering and you have to handle a bigger number of ideas for evaluation, it proofed to be useful to add the ideas to a Portfolio Diagram where the x-axis represents the effort for creating a patent and implementing the technical solution and the y-axis represents the expected benefit or the expected potential of the patent. Both axis use the values low, middle and high to span the Portfolio Diagram (see Figure 8)

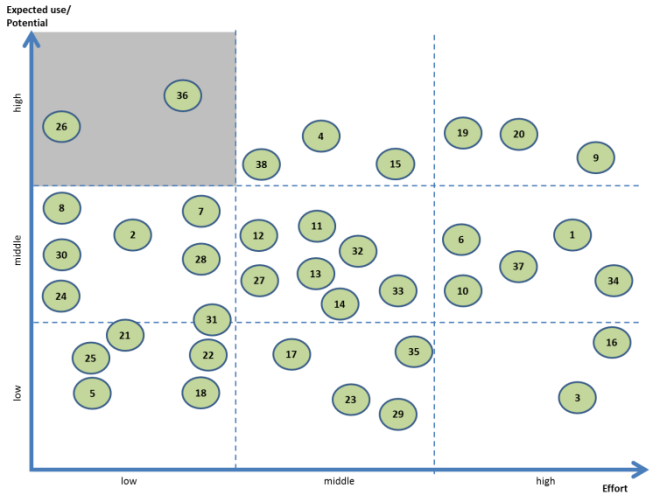


Figure 8: Portfolio Diagram for idea evaluation with the “sweet spot” for first consideration

Normally, first to address are those ideas that are marked in Figure 8 with low effort and high benefit. Others will be scheduled for later to work on. But this depends on the intended strategy of the workshop owner. With this step the workshop ends. The results are documented by the facilitator.

2.4.3. Documentation

As every workshop can be handled as a small project, the documentation for the whole process has to be done. The documentation should include also the updates that were made to the prepared materials during the workshop as they are:

- Innovation Situation Questionnaire
- Problem Formulator Model(s)
- Directions for Innovation
- Full listing of Ideas
- Evaluation of Ideas

3. Summary and results

Interestingly TRIZ - or in this special case the Inventive Problem Solving Process according to Ideation Inc. - is not only suitable for solving problems, but also for creating ideas for new inventions and, resulting from this, new patents.

Within the last two years about 20 workshops of this kind have been conducted at thyssenkrupp in different business units, boosting the number of invention reports in just the right technology areas while at the same time introducing IP not just for securing technical solutions, but also as a structured and inspiring approach to find new solutions.

References

[1] Terminko, J.; Zlotin, B.; Zusman, A.: Systematic Innovation: An Introduction to TRIZ (Theory of Inventive Problem Solving) (APICS Series on Resource Management) 1st Edition 1998 ISBN-13: 978-1574441116

[2] Schlicksupp, H.: Ideenfindung: Innovation, Kreativität und Ideenfindung Vogel Business Media/VM; Auflage: 5., überarb. u. erw. Aufl. (1998); ISBN-13: 978-3802317866

[3] Saaty, Th. L.: Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World, New Edition 2001 (Analytic Hierarchy Process Series, Vol. 2) Paperback; RWS Publications; 3rd Revised edition September 3, 2012; 978-0962031786

How to Generate Simple Model Solutions Systematically from Function Analysis Diagram

Min-Gyu Lee[a,b]

[a]*School for Business and Management, Lappeenranta University of Technology, Skinnarilankatu 34, Lappeenranta 53851, Finland*
[b]*QM&E Innovation, 34 Hwangsaeul-ro 200, Bundang-gu, Seongnam-si, Gyeonggi-do, 13595, South Korea*

Corresponding author. Tel.: +82-10-8917-7057; fax: +82-31-713-0052. *E-mail address:* alex.mglee@gmail.com

Abstract

Function Analysis (FA) and Cause Effect Chain Analysis are among the most important and central tools in analysis phase of a TRIZ based inventive problem solving project. FA is useful for understanding the technical system and its problems. But the process of generating ideas directly from FA has not been so obvious or convenient for many TRIZ users – except for the cases of using FA together with the methods of trimming or Function Oriented Search. The goal of this study is to provide a new, more convenient and systematic method of generating ideas directly from FA diagram. This goal is accomplished by connecting FA with a set of simple Model Solutions extracted from Inventive Standards. The process of using this new method, named Function Analysis Plus (FA+), can be summarized as follows. 1. Draw the As-Is FA Diagram or FA+ diagram (which can represent the causality, different times or occasions) 2. Select an unsatisfactory action and classify it as one of the 2 Model Problems. Select feasible ones from the 2 or 5 Model Solutions for it considering the constraints. 3. Repeat step 2 for all the important unsatisfactory actions. 4. Develop each feasible Model Solutions into one or more concrete ideas by identifying suitable substance field resources and/or their needed properties. The process of using this method and its usefulness is demonstrated with a case study.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Function Analysis; Inventive Standards; Substance Field Analysis; Su-Field Analysis; TRIZ

1. Introduction

An early version of Function Analysis was first developed in General Electric in 1940s to reduce cost while keeping the useful functions of the system [1]. It was adopted into modern TRIZ methodology and developed further in 1990s [2, 3, 4].

In a modern TRIZ based inventive problem solving project, Function Analysis (FA) and Cause Effect Chain Analysis (CECA) [5] play the most central roles because they check and push the team's understanding of the system, problem and its causes and provide big directions of idea generation.

Comparing the two methods, CECA is more flexible and can include any kind of causes but it is somewhat subjective and requires high level of knowledge on the system and technology, logical and unbiased thinking. Once it is drawn, solving directions can be generated semi-automatically [6].
On the contrary, since FA deals with the real components and their real interactions, it seems to be more objective and gives the user more opportunity to stay unbiased. FA can be helpful in pushing the user to understand the hidden mechanism of useful and harmful functions of the system.

FA is useful in idea generation also. Since FA deals with not only what the system is composed of (components) but also what they do (functions), it is not fully restricted by current design of the system but can help users find new and better ways of doing the useful function when used together with the methods of Trimming or Function Oriented Search.

But except for those cases, the process of idea generation from FA was not clear or convenient enough. The goal of this study is to provide a new, more convenient and systematic method of generating ideas directly from FA diagram.

This was done by connecting FA with a simplified version of Inventive Standards (IS) [7]. IS surely is a huge and useful collection of model problems, model solutions and their connections but we only need a much simpler version to make it easy to memorize and use in FA. Many authors have tried to

improve the inventive standards in many ways but most of them did not try to connect it directly and graphically with FA diagram to generate ideas, even though a Su-Field Model is very similar to one or two segments of a Function Diagram.

The most helpful approach for this purpose was Iouri Belski's version of Su-Field Analysis and Simple Model Solutions [8]. While Belski's Method is using a FA Diagram with the arrows replaced by triads as in Su-Field Model, FA+ more closely follows the FA Diagram conventions except for a few minor modifications. FA+ was inspired by simple Model Solutions (MS) of Belski's Method but the classification is redefined after merging some and adding another.

The new method was developed from efforts to strengthen the connection between FA and IS and to improve each methods to be more suitable for this connection – FA, IS and Belski's method. The new method is named as Function Analysis Plus (FA+) as a companion of a similarly modified practical version of CECA (CECA+) by the author and others [6]. But before describing FA+, the reasons why these two methods were not fully utilized are investigated below.

2. Directions for Better Utilization of Existing Methods

Two cause effect chain analyses were conducted to investigate the causes "why the potential strength of Function Analysis (Inventive Standards) is not fully and conveniently utilized". The main causes (rectangles) and directions for improvement (clouds) are highlighted in Fig. 1 and Fig. 2 in thicker borders. The findings are not repeated here as they are clearer in the CECA diagrams.

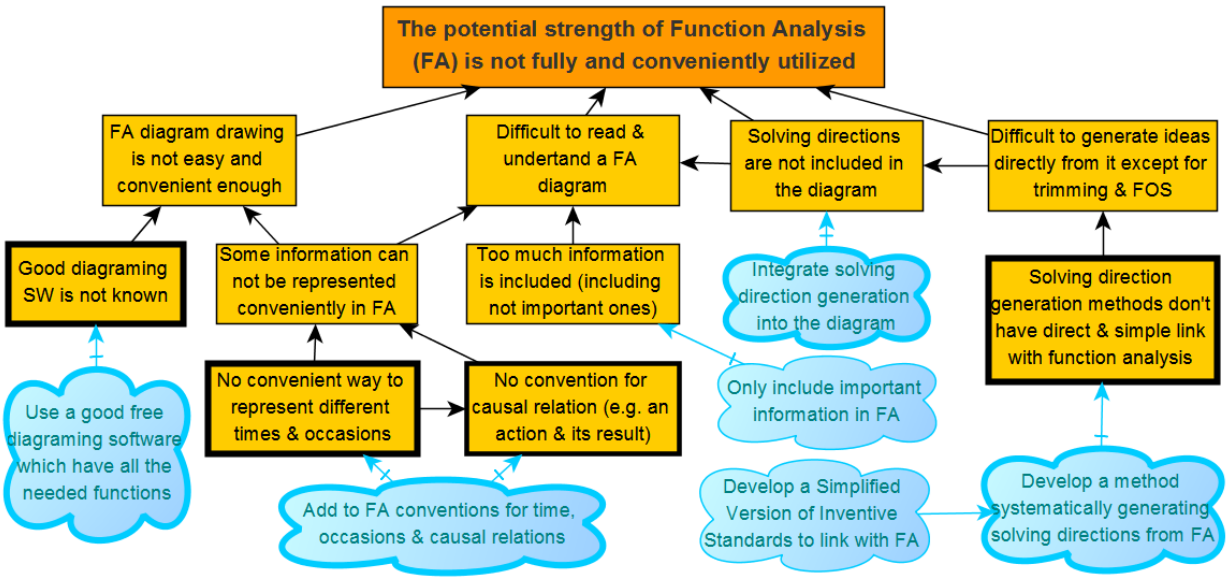


Fig. 1. Cause-Effect Chain Analysis + Diagram for fuller utilization of potential of the method: FUNCTION ANALYSIS. (Rectangles: Disadvantages and/or Causes, Clouds: Directions for Improvement)

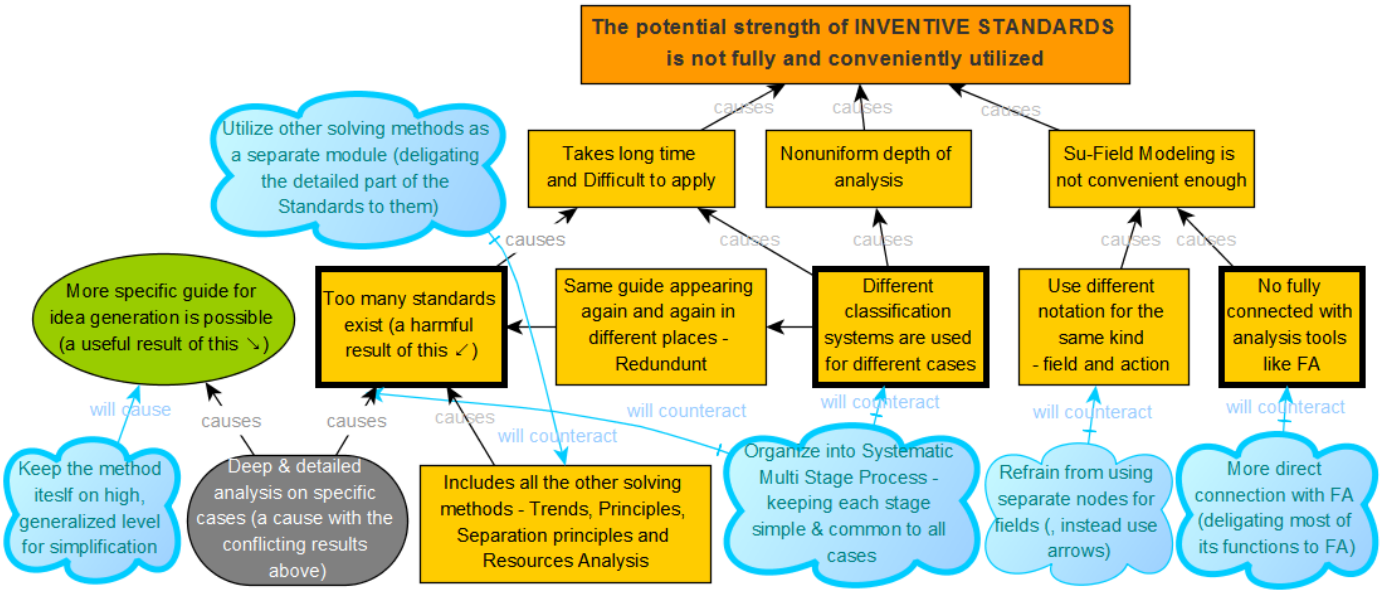


Fig. 2. Cause-Effect Chain Analysis + Diagram for fuller utilization of potential of the method: INVENTIVE STANDARDS. (Rectangles: Disadvantages and/or Causes, Clouds: Directions for Improvement, Stadium: Contradiction, Ellipse: Useful Result)

3. Introduction to Function Analysis Plus (FA+)

3.1. Introduction and Drawing Conventions

The new method was developed according to the findings of the two CECA in previous section. But the majority of its conventions and theoretical contents comes directly from the existing methods of FA, Standards, Su-field Analysis and other methods of TRIZ. In Fig. 3, the drawing conventions of FA+ which is almost identical with existing methods were summarized. An 'unsatisfactory action' is defined to be either a harmful action or a useful action which is either insufficient, excessive or unsatisfactory.

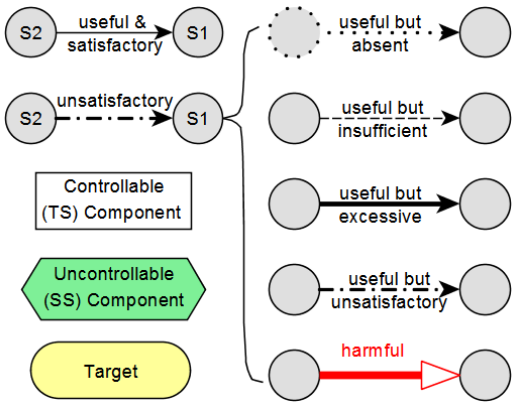
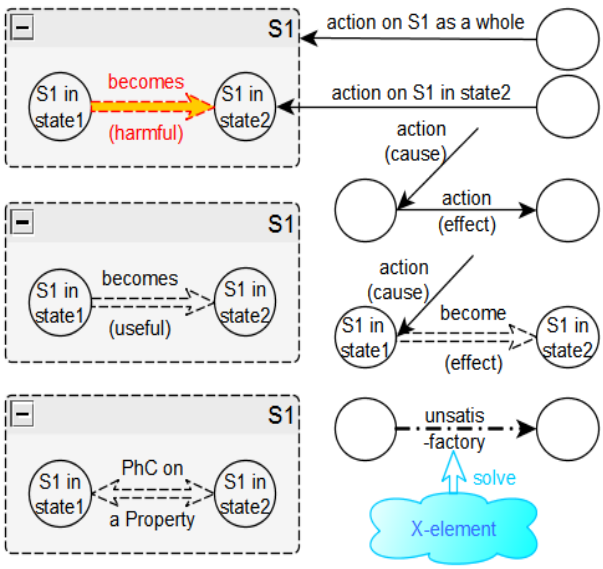


Fig. 3. Drawing conventions for components, substances and actions used in FA+ and in definition of model problems and solutions. (TS: Technical System, SS: Super System, S1: Object, S2: Tool)

All these diagrams in this paper were drawn with a free drawing software called yEd [9]. It is fast, convenient, versatile and customizable and has all the functions needed for FA+ and other diagrams for TRIZ.

In Fig 4, the drawing conventions newly added to FA+ are summarized. The conventions (a) for Time and Occasion try to add a way to express situations from different times and different occasions in a diagram. The former is to overcome the snapshot-like limitation of FA. It would be especially convenient to draw a movie-like process in a diagram. For example, to draw a conventional FA diagram for a water supply line, too many arrows will direct to 'water' because water interacts with all parts of pipes, tanks and valves. But in FA+ diagram, the water in different parts can appear as different components connected with each other with a double arrow "becomes" and each interacting with a smaller number of neighboring components than before. This will make the diagram more understandable. The convention for occasions will be useful to represent a physical contradiction with two different states of the same component.



(a) For Time & Occasion (b) For Causality & Solving Direction

Fig. 4. New Drawing Conventions in FA+

The conventions in the middle of (b) was added to represent causality. Since some of the actions and transformations (in time) have causal relations with each other, connecting these pairs of arrows (head to tail) can naturally make the flow of cause-effect actions very clearly visible. Convention with solving directions will be explained more in the next section.

3.2. How to Build the Model and Analyze in FA+

The process of analyzing a problem and generating solving directions using FA+ method can be summarized as follows.

1. Identify the technical system to improve and define the problem and goal.

2. Build an As-Is FA (+) Diagram for the problem situation. It can be a conventional FA diagram or an FA+ diagram with new conventions in Fig 4 showing the initial situation of the problem.

3. From the diagram, select one of the unsatisfactory actions (arrows) which are important for solving the problem and do the following steps with this arrow.

   A. Identify which of the 2 model problems (MP1 and MP2 in table 1) the selected action corresponds with.

   B. Test whether each of the model solutions (MS1-1~2 or MS2-1~5 in table 1) for the selected model problem is feasible. Often, the problem situation and constraints prohibit some of the model solutions. Then draw the feasible model solutions in the FA+ diagram as clouds with the name of model solutions and hollow arrows directing to the unsatisfactory actions that they are addressing to solve.

4. Repeat step 3 for all the other unsatisfactory actions that are important for solving the problem. This will complete the FA+ diagram with feasible model solutions (or 'solving directions').

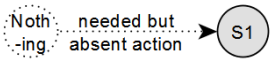
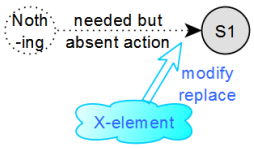
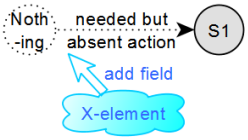
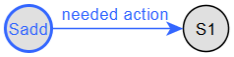
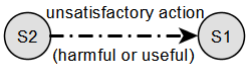
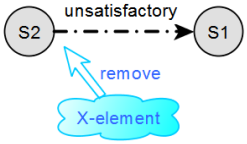
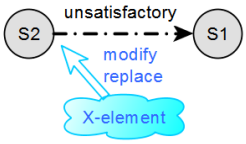
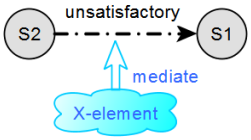
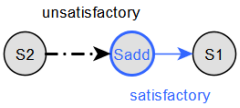
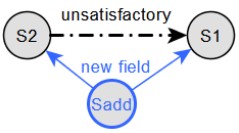
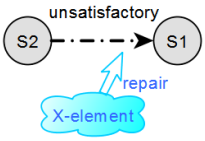
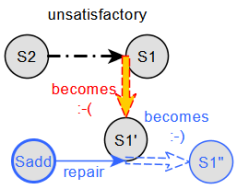
5. Try to match suitable resources (substances and fields) for each feasible model solutions. They can

be searched initially from the FA itself with the help of a few trends of evolution (e. g. MATChEm and Macro to Micro etc.). A model solution (solving direction) with a well-defined set of substance and field can be called an idea. An idea can also be drawn in FA as a cloud.

3.3. The Model Problems and Model Solutions of FA+

Most of the Model Problems and Model Solutions are just reclassification of the ones already existing in IS or other TRIZ methods. The new classification is designed to be as simple as possible so that an average TRIZ user can memorize and use it in FA diagram but still helpful enough to generate main solving directions existing in IS or other TRIZ methods.

Table 1. Two Model Problems and Seven Model Solutions for FA+

Model PROBLEM (MP)	Model SOLUTION (MS)	Expression of MS in Diagram	Meaning of MS	Comment
MP1. Needed but Absent Action There is a needed but absent action on a Substance S1. (Sometimes caused by the result of applying MS2-1. Removing) 	**MS1-1. Modify or Replace Substance** Modify the properties of the substance S1 or Replace it with other substance S_{add} so that the action is not needed any more.		= 	Modification (S1") or Replacement (S_{add}) of S1 should no longer need the action.
	MS1-2. Add a Tool (a Field Adder) Add a new tool (field adder) S_{add} that can provide the needed action on S1.		= 	The new tool S_{add} provides the needed action on S1.
MP2. Unsatisfactory Action A substance S2 has an unsatisfactory action (either harmful or useful) on another substance S1. Sometimes S2 could have other useful action that must be preserved. 	**MS2-1. Remove Substance** Just remove S2 (or S1, or both). If they have only harmful functions and removable, just removing them can solve the problem.		= 	If a 2ndary problem MP1 (Needed but Absent Action) is generated by application of MS2-1 or 2-2, go to try application of MS1's. The method of trimming corresponds to "Replace" in MS2-2
	MS2-2. Modify or Replace Substance Modify the properties of the substance S2 (or S1, or both), or replace it with another substance S_{add} so that all actions by or on it become satisfactory.		= 	
	MS2-3. Add a Mediator Add a substance S_{add} that can mediate the field (or action) from S2 to S1 (to amplify, attenuate, filter, stop, remove, control, transform or deflect it)		= 	Both MS2-3 and 2-4 add a substance S_{add} in the interacting pair. In 2-3, S_{add} is a field mediator, whereas, in 2-4, S_{add} is a carrier of a new field (which is not a modification of the original field).
	MS2-4. Add a Tool (a Field-Adder) Make the action satisfactory by creating a helping field (or action) (on S1, S2 or both) by adding a tool S_{add} to the interacting pair		= 	
	MS2-5. Repair S1 Later Leave the unsatisfactory action change S1 to S1' (S1 in an unsatisfactory state) and repair S1' later by adding a tool (field-adder) S_{add} acting on S1' to change it to S1" (S1 in a repaired, satisfactory state)		= 	Often, repairing (or post treatment) is the least efficient way of solving the problem but sometimes it's useful.

The head of hollow arrow from X-element cloud should be located on the arrow corresponding to the unsatisfactory action. The position of the head of the hollow arrow along the arrow for the unsatisfactory action further shows upon which substance the MS will be applied – S1, S2, either or both.

If a secondary problem is generated by application of a MS, reclassify this secondary problem as either MP1 or MP2 and try to find MS's again to solve them.

The MS's are sorted and numbered s. t. the MS with smaller numbers have statistically higher ideality if applicable. The maximum number of verbs beside an arrow from a cloud is 6 (modify, replace, mediate, add field, remove and repair) but practically max. 4 verbs may be used since the last two verbs are rarely used.

To achieve the smallest but useful set of models, the following strategy was chosen after many revisions and tests.

- The model does not distinguish the detailed 'kinds' of unsatisfactory actions – insufficient, excessive, other unsatisfactory useful actions (with unsatisfactory intensity, polarity, direction, distribution in space-time or object etc.) or even harmful actions, because the possible set of model solutions for each of the kinds are all very similar.

- The substance that an MS can change is often automatically restricted by the constraints of the problem situation. Usually MS can change only the technical system components and not the supersystem components. Exactly speaking, in FA+, it is better to select the shape of the components according to the controllability or changeability of the component to solve the problem. It is even better if we add one more symbol, an octagon for example, representing a component with an intermediate level of controllability. In this case, one can focus only on the fewer number of rectangular components which is easiest, cheapest and safest to change.

- A modification of a substance includes changing the properties of the substance (but not the substance itself) while design change for solving the problem. The property can be the amount or state of the particles constituting the substance, their distribution in space time, type of links between them or their reaction w.r.t. any kind of fields etc.

4. A Case Study of Application of FA+

The section introduces how FA+ method is used in a coaching project which is easy to understand. Since the basic conventions were already introduced in section 3, here we will more focus on the context, thinking process and related tips. Some simplification has been done.

4.1. Initial Situation and the Problem Definition

An Indoor Driving Range is a place where golfers can practice driving shots as in Fig 5. There are tall steel truss pillars so all the walls and ceiling are covered with huge nets which can keep golf balls from flying out of the driving range. The problem is that in winter when there is a heavy snow stacking on the roof net, sometimes the steel truss cannot withstand the weight and collapse. How to improve the design of such driving range to be safe from heavy snow?

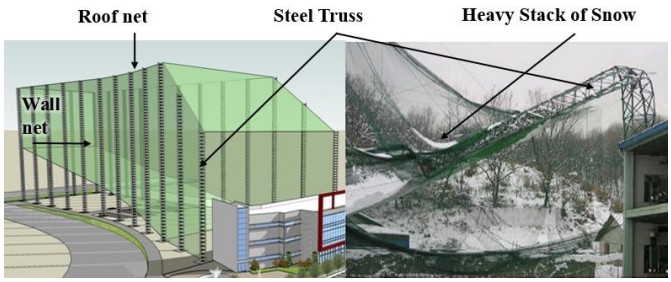


Fig. 5. An Indoor Driving Range with Nets (a) Normal (b) Collapsed

4.2. Building an As-Is Function Analysis (+) Diagram

After some preliminary investigation, a FA+ diagram is built as in Fig 6. Here, several new conventions are used.

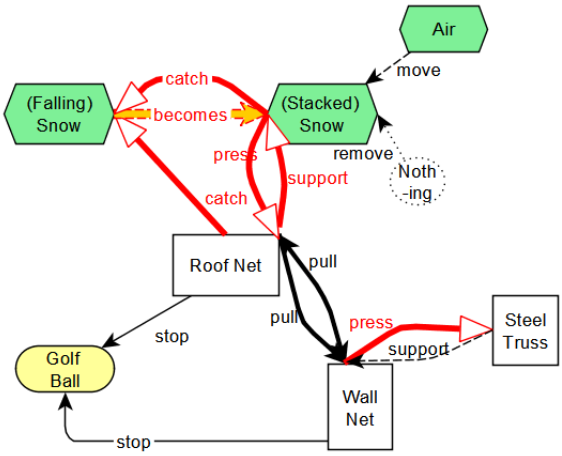


Fig. 6. As-Is FA+ Diagram (with conventions for time and causality)

- An arrow for an absent useful function is also drawn to provide a location for the problem and its solving directions.

- The same snow in two different times, 'falling snow' and 'attached snow', were expressed separately. All the other components were not doubled because their change in time is small or not important for solving this problem.

- If one arrow (actions or transformations) starts from exactly at the end of another arrow, it means that there are CAUSAL RELATIONS between the connected arrows. Because they are connected, the "chain" of causally related actions are easily visible as in Fig. 6.

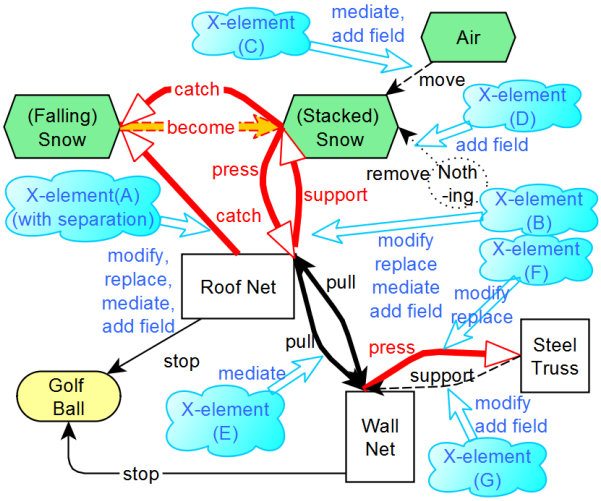


Fig. 7. Adding Feasible Model Solutions to FA+ Diagram

The best solutions is often generated near the 1st arrow of the chain of causally related unsatisfactory actions (in this case, roof net's function of 'catching falling snow'). This 1st arrow, called a key (root) unsatisfactory action, is closely related with a key disadvantage (or root cause) in CECA.

4.3. Adding Feasible Model Solutions in FA+ Diagram

Model Solutions are searched starting from the root cause related the key action "catching snow" of the roof net. Since it is a harmful action, it is classified as MP2 in the classification of table 1. After testing feasibility of model solutions MS2-1~5, MS2-2~4 are found to be applicable with a focus to the roof net since the falling snow is less controllable. Continuing this search for feasible Model Solutions along the chain of 7 unsatisfactory actions, 7 X-elements are drawn with a total of 16 feasible model solutions if we count "modify" and "replace" separately.

If the feasible model solutions found are too many, it is possible to focus on more promising Model Solutions located near the root of unsatisfactory action chains. Or one can focus on the first few model solutions which has often higher ideality. Or one can reduce the scope of 'controllable' components to minimize cost or difficulties.

4.4. Developing Ideas along each feasible Model Solutions

A feasible Model Solution is just a rough direction for solving – e.g. 'How can the roof net be modified so that it will not catch the falling snow?' or 'What substance can be added or used to generate which field to remove the stacked snow?' To answer these questions and get concreate ideas for solutions, we need to find the exact properties to change, the exact field to generate and the exact substance to use to generate this field. One can easily find the best resources for each model solutions by searching nearby components in the FA+ diagram. Or one could conduct a full research analysis by building a table as in ARIZ. Some of the ideas generated in this way are added to the FA diagram in Fig 8 below.

5. Conclusion

The author have been using FA for many years and using FA+, including several previous versions of the author, since last year in many consulting or coaching projects and in team exercises during TRIZ education. Comparing the number and diversity of ideas and the efficiency of idea generation process of the two methods, FA+ showed much improvement than the conventional FA method, both for level 2~3 students and for the consulting team where the author belongs to.

Acknowledgements

I would like to acknowledge the TEKES Finnish Funding Agency for Innovation and its Finnish Distinguished Professor (FiDiPro) program for supporting the research. I would also like to thank Professor Leonid Chechurin in Lappeenranta University of Technology and TRIZ masters Vasily Lenyashin and Yury Danilovskiy in QM&E Innovation for their teaching and guide to this exciting field. Their insight and expertise greatly helped this research, although they may not agree with all of the explanations and conclusions of this paper.

References

[1] Lawrence D. Miles, Techniques of Value Analysis and Engineering, 1961 (or 3rd Edition, Lawrence D. Miles Value Foundation, 2015)
[2] S. Litvin, N. Feygenson and O. Feygenson, Advanced Function Approach, 10th ETRIA World TRIZ Future Conference, 2010. vol 9. Elsevier, 2011, p 92–102
[3] Gerasimov V.M., Litvin S.S., Basic statements of methodology for performing function-cost analysis: Methodological, Moscow: Inform-FSA, 1991 (in Russian).
[4] Devoino I.G., Koshevoy O.E., Litvin S.S. and Tsourikov V., Computer Based System For Imagining And Analysing An Engineering Object System And Indicating Values of Specific Design Changes, United States Patent 6056428, filed 1997.
[5] S. Litvin and B. Axelrod: "The method of constructing causal chains of undesirable effects", Manuscript, Saint-Petersburg: IMITsentr, 1996, 4c. (in Russian)
[6] M. G. Lee, L. Chechurin and V. Leniachine, Improvement of Cause Effect Chain Analysis, CECA+, for systematic cause analysis and semi-automated idea generation for inventive problems, Flexible Automation and Intelligent Manufacturing 2016
[7] G. Altshuller. Inventive Standards 76, 1985 (in Russian)
[8] I. Belski, Improve Your Thinking: Substance-Field Analysis, Melbourne: TRIZ4U; 2007
[9] https://www.yworks.com/products/yed (accessed June 20, 2016).

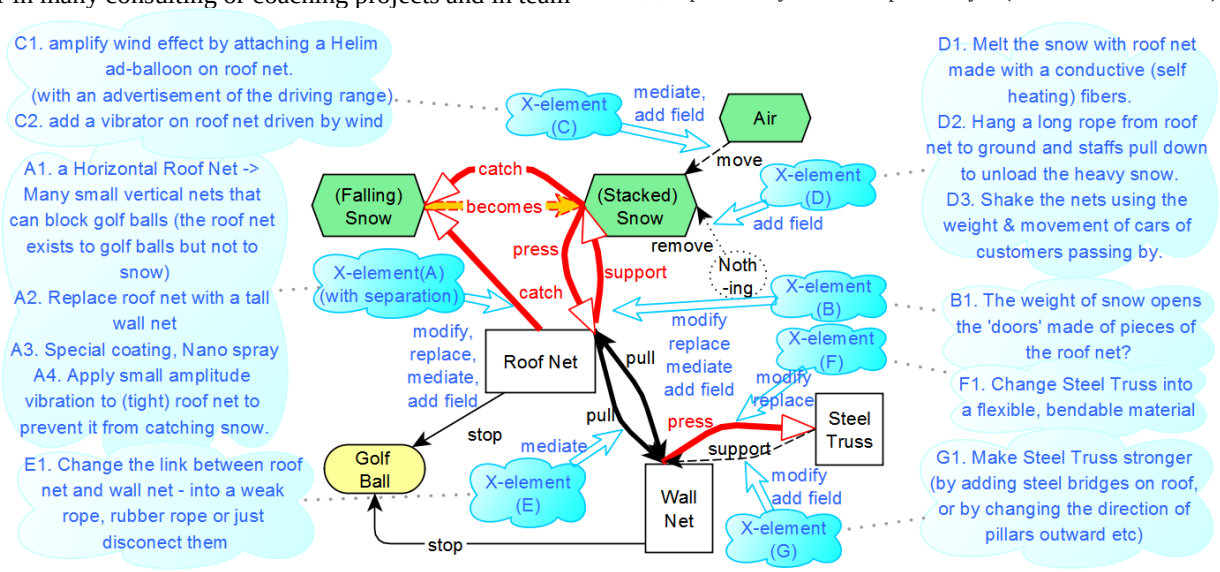


Fig. 8. Adding Ideas for each Feasible Model Solutions to FA+ Diagram

Is Poland an innovative country?

Dorota Chybowska[a], Leszek Chybowski[b,*]

[a]*Maritime University of Szczecin, Technology Transfer Office, 1-2 Waly Chrobrego St., 70-500 Szczecin, Poland*
[b]*Maritime University of Szczecin, Faculty of Marine Engineering, 1-2 Waly Chrobrego St., 70-500 Szczecin, Poland*

* Corresponding author. Tel.: +48-91-480-94-12; fax: +48-91-480-95-75. *E-mail address:* l.chybowski@am.szczecin.pl

Abstract

The potential for innovativeness is difficult to measure, though many have attempted to do so. In order to look at Poland's innovation potential, its current position and its opportunity to grow, compared with developing and developed countries, this study analysed the patent statistics of the Polish and European Patent Offices. Poland has been a member of the European Union for over a decade now. Therefore, we took into consideration the statistics for patent applications and grants for the last decade, up to the first quarter of 2016. The questions we wanted to answer concerned not only the technology fields that Poland patented its inventions in, but also the types of patent grantees and applicants. In order to determine why Poland is still considered to be only a moderate innovator by the Innovation Union Scoreboard, we also gathered information on Polish inventors abroad in 2015 and the first quarter of 2016, to see their number, technology fields, and types of patent grantees. Finally, we attempted to identify the main barriers that seem to inhibit Polish technology and innovation growth, despite significantly growing R&D intensities (up from 0.56 GDP and EUR 1,139 M in 2004 to 0.94 GDP and EUR 3,864 M in 2014).

ISSN 1866-4180
Peer-review under responsibility of scientific committee of TRIZ Future Conference 2016.

Keywords: innovativeness potential; inventions; patent mining; innovation; Poland

1. Introduction

As Genrich Altshuller observed, "inventing is the oldest human activity" [1]. Humans have always faced problems to solve otherwise they would not have advanced. We could attempt to categorise inventions into cutting-edge, unique, lucrative, local, global, etc. while searching for the motivators that bring them to light. Regardless of their origin, however, inventions are an expression of human creativity, concentration, reasoning and critical thinking.

Pursuant to international treaties, a patent is a confirmation of novelty and usefulness of an invention for the state of the art.

It is also an exclusive right granted to the inventor. Disclosing an invention to a patent office in return for an inventor's monopoly to use it has equally many supporters and opponents. On the one hand, the patent system is easily accessible and open, whereas on the other it discloses inventive ideas to competitors.

We could provide many examples of patent wars, not only those of the 20th and 21st centuries, and discuss whether or not they affected technological progress. Undoubtedly, without the exchange of ideas through disclosing inventions, we would not move forward and the wheel would have to be reinvented not once but an infinite number of times.

Altshuller, who introduced the theory of inventive problem solving, claimed that every person can become an inventor. Not necessarily a good one, but an inventor nevertheless. Our paper does not conclude which nation is the world's most inventive one. Although we would like to know this ourselves, we fear that answering this question is impossible. In this paper we concentrate on our own country and we attempt to show the place of Polish inventive problem solving and Polish inventors in the system of invention disclosure exchange in the last decade. The purpose of the paper is to offer a review of the statistics of Polish and European Patent Offices for the last decade and to compare Poland to other countries in terms of inventions, inventive potential and barriers. We also test the hypothesis that Polish inventors invent abroad. Despite growing Polish R&D intensities, the world still considers Poland a

moderate innovator and every year many statistics appear to support this view.

2. Poland versus other countries

Poland, with its 38.5 M inhabitants, is the 6th largest country in the European Union by population, after Germany, France, UK, Italy and Spain [13]. In 2014 there were 1,469,386 Polish university graduates and 319,019 of them graduated from technical universities, which makes 21% of all graduates [9]. Moreover, Polish R&D intensities grew from 0.56 GDP and EUR 1,139 M in 2004 to 0.94 GDP and EUR 3,864 M in 2014 [8] while R&D personnel numbered 153,500 in 2014 [3].

To assess if the Polish potential expressed by its population, number of university graduates, R&D personnel and growing investments in the R&D sector correlates with the number of inventions, we analysed statistics published by the Polish and European Patent Offices. We considered the number of applications and granted patents between 2006 and 2015, filed by and given to both Polish and non-Polish grantees.

Tables 1 and 2 present the number of applications and patents granted by the Polish Patent Office (UP RP), respectively. The annual number of applications to the UP RP in the period 2006–2015 increased by more than 100% for Polish applicants. For foreign applicants, the annual number of applications decreased, from 212 in 2006 to 99 in 2015. In percentage terms: in 2006 Polish applications made up 91.0% of all applications, and in 2015, 98.0%; and in 2008 foreign patent grantees made up almost 60.0% of the total, while in 2015 they only accounted for 6.5% of grantees.

Table 1. Polish Patent Office (UP RP) – number of applications 2006–2015 (source: Authors' analysis based on [2, 12]).

Year	2006	2007	2008	2009	2010
Polish	2157	2392	2488	2899	3203
Foreign	212	214	232	241	227
TOTAL	2369	2606	2720	3140	3430
Year	**2011**	**2012**	**2013**	**2014**	**2015**
Polish	3878	4410	4237	3941	4674
Foreign	245	247	174	155	99
TOTAL	4123	4657	4411	4096	4773

Table 2. Polish Patent Office (UP RP) – number of patent grants 2006–2015 (source: Authors' analysis based on [2, 12]).

Year	2006	2007	2008	2009	2010
Polish			1451	1536	1385
Foreign	2686*	3534*	2139	2422	1619
TOTAL	2686	3534	3590	3958	3004
Year	**2011**	**2012**	**2013**	**2014**	**2015**
Polish	1989	1848	2339	2490	2404
Foreign	1123	636	465	262	168
TOTAL	3112	2484	2804	2752	2572

Tables 3 and 4 show the annual number of applications and patents granted by the European Patent Office (EPO) between 2006 and 2015.

Data analysis shows that Polish patent applications increased 4.5 times between 2006 and 2015 while the number of patent grants to Polish grantees increased 8.8 times. However, the absolute number of Polish patent applications and grants is insignificant when compared to the totals of applications and grants by the EPO in the period: Polish applications to the EPO in 2015 equalled 0.35% of the total number of applications while the number of patents granted to Polish grantees amounted to 0.22%. These data clearly indicate that Polish applicants get patents locally – they patent inventions 16 times more often in Poland than through the EPO. The number of patents granted to Polish owners by the EPO equals only 6.0% of patents granted to Polish owners by the UP RP.

Table 3. European Patent Office (EPO) – number of applications 2006–2015 (source: Authors' analysis based on [6, 7]).

Year	2006	2007	2008	2009	2010
Polish	125	104	168	174	205
Foreign	135233	141127	146076	134337	150810
TOTAL	135358	141231	146244	134511	151015
Year	**2011**	**2012**	**2013**	**2014**	**2015**
Polish	246	383	372	482	568
Foreign	142576	148179	147655	152221	159454
TOTAL	142822	148562	148027	152703	160022

Table 4. European Patent Office (EPO) – number of patent grants 2006–2015 (source: Authors' analysis based on [6, 7]).

Year	2006	2007	2008	2009	2010
Polish	17	27	26	33	44
Foreign	62760	54673	59774	51919	58073
TOTAL	62777	54700	59800	51952	58117
Year	**2011**	**2012**	**2013**	**2014**	**2015**
Polish	45	80	95	108	150
Foreign	62063	65575	66617	64505	68271
TOTAL	62108	65655	66712	64613	68421

In Figure 1 we present a comparison between Poland and selected developed countries in terms of patent grants by the EPO.

Statistical analysis revealed that 22.15% of all patents granted by the EPO in the period were American (USA), 21.32% German, 18.21% Japanese, 7.56% French, 2.34% South Korean, 1.15% Finish and 0.99% Chinese.

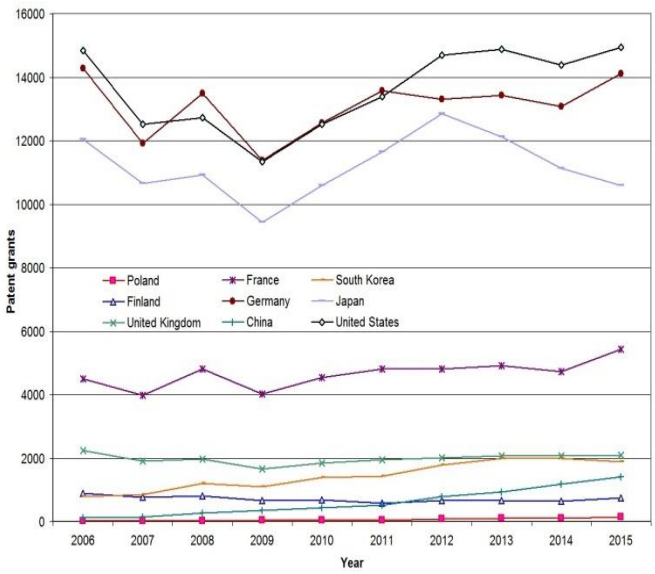


Fig. 1. Poland vs. selected developed countries – patent grants by the European Patent Office (EPO) 2006–2015 (source: Authors' analysis based on [5, 7]).

As seen in Figure 1, countries from the same region (here, Asia) can differ significantly. Awareness and intellectual property rights (IPR) culture might be the underlying reason for these differences. Polish patents amount to only 0.10% of the total number of patents granted by the EPO in the period.

3. Type of grantee

The available reports [5] indicate that in Poland the governmental sector still has the biggest share in the R&D financing structure (45.2% in 2014). The share of the private sector increased to 39.0% (i.e. by 14.6 percentage points) in comparison to 2010. The research (educational) sector invests the least in R&D (2.2%) [3]. Concerning the internal R&D expenses by sector, the private sector leads the way at 47.0%, with the research sector at 29.0% and governmental at 24.0%.

Figure 2 shows the results of our analysis of patents granted in 2015 and the 1st quarter of 2016 by the EPO to Polish and foreign grantees, but with a Polish (co)inventor. It also shows that in terms of the type of patent grantee, enterprises take the lead (both Polish and foreign with a Polish (co)inventor). The research sector is placed second, but its figures refer exclusively to Polish patent owners.

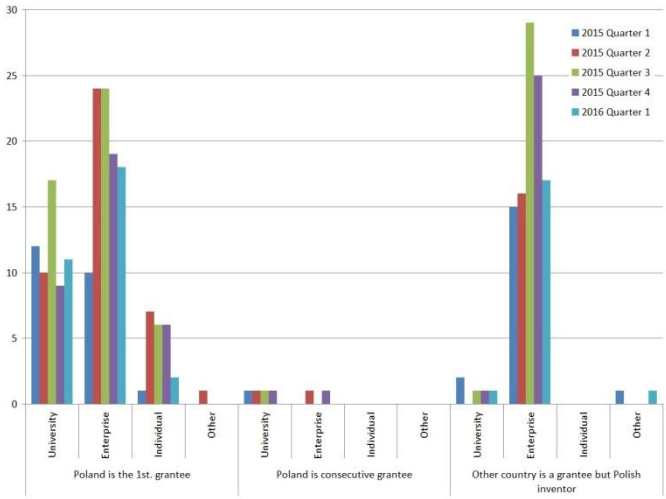


Fig. 2. Distribution of patents granted in 2015 and the 1st quarter of 2016 by the European Patent Office (EPO) to Polish grantees and foreign grantees with Polish inventors (source: Authors' analysis).

Table 5 shows the ranking of the top 5 Polish grantees in the EPO in 2015. The most patents were granted to enterprises, with International Tobacco Machinery Poland Sp. z o.o. from Radom and FAKRO PP Sp. z o.o. from Nowy Sącz leading the field. Other enterprises making up the total received 1–2 patents each.

The position of the research sector is also strong, both in terms of patent grants, as shown in Table 5, and (according to the information presented in [7]) patent applications: in 2015 Gdańsk University of Technology filed the most patent applications (23), followed by AGH University of Science and Technology in Cracow (22), International Tobacco Machinery Poland Sp. z o.o. (14) and HS Wrocław Sp. z o.o. (11).

Table 5. European Patent Office (EPO) – Ranking of Top 5 Polish grantees in 2015.

Grantee	Status (E, R, I, O*)	2015
International Tobacco Machinery Poland Sp. z o.o., Radom, Mazovian	E	9
AGH University of Science and Technology Cracow, Lesser Poland	R	6
FAKRO PP Sp. z o.o. Nowy Sącz, Lesser Poland	E	6
Institute of Immunology and Experimental Therapy Polish Academy of Sciences, Wrocław, Lower Silesian	R	4
Warsaw University Warsaw, Mazovian	R	4
TOTAL		**29**

*E for enterprises, R for universities, research institutes, I for individual grantees, O for other types (NGO, hospital etc.)

In the UP RP, the research sector dominates as a patent grantee. Table 6 presents the ranking of the top 5 grantees in the 1st quarter of 2016.

Table 6. Polish Patent Office (UP RP) – Ranking of Top 5 grantees in 1st quarter of 2016.

Grantee	Status (E, R, I, O*)	Patents
Wrocław University of Technology Wrocław, Lower Silesian	R	20
AGH University of Science and Technology Cracow, Lesser Poland	R	18
Lublin University of Technology Lublin	R	15
West Pomeranian University of Technology Szczecin, West Pomeranian	R	14
Warsaw University of Technology Warsaw, Mazovian	R	13
TOTAL		**80**

*E for enterprises, R for universities, research institutes, I for individual grantees, O for other types (NGO, hospital etc.)

To compare, we also analysed foreign grantees in the Polish Patent Office (UP RP) in the 1st quarter of 2016 as shown in Table 7. Most patents (93%) were granted to enterprises.

Table 7. Polish Patent Office (UP RP) - Ranking of Top 5 foreign grantees 1st quarter of 2016

Grantee	Status (E, R, I, O*)	Country	Patents
VKR Holding A/S	E	Denmark	4
General Electric Company	E	USA	3
Joy MM Delaware, Inc.	E	USA	3
Soho Flordis International Pty Ltd.	E	Austria	3
Janssen Pharmaceutica N.V.	E	Belgium	2
TOTAL			**15**

*E for enterprises, R for universities, research institutes, I for individual grantees, O for other types (NGO, hospital etc.)

In the 1st quarter of 2016, the Polish Patent Office granted 607 patents, 44 of which were to foreign owners (mostly from the USA – 17 and Germany – 9). As for Polish grantees, 287 patents were granted to universities and research institutes (47.0% of all granted patents), 186 to enterprises (31.0%) and 89 to individuals. Polish patents make up 93.0% of all patents granted by the Polish Patent Office in the 1st quarter of 2016.

4. Regional distribution of Polish patent grantees

Poland consists of 16 administrative districts (voivodeships). Both Polish and European statistics for 2015, shown in Figure 2, place Mazovian, Silesian and Lesser Poland voivodeships as leaders of invention disclosure.

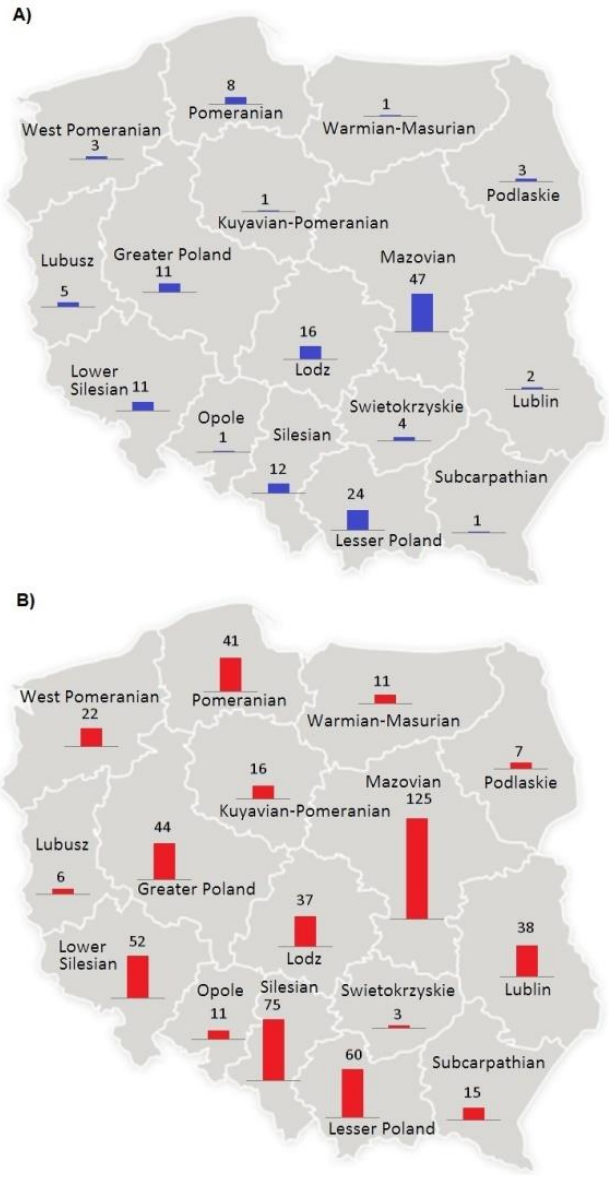


Fig. 3. Regional distribution of Polish patent grantees in 2015; (A) – European Patent Office (EPO), (B) – Polish Patent Office (UP RP).

According to [6], in 2015 the leading geographic regions in Poland, in terms of patent applications, were Mazovian (149 applications; 26.0% share in all Polish applications), Lesser Poland (79; 14.0%) and Pomeranian (70; 12.0%).

5. Polish inventors

To investigate why the number of Polish patents is still so low at the European level (163 from 01 Jan 2015 to 31 March 2016), we analysed data from the EPO for the same period and compared the results with the number of foreign grantees where a Polish inventor was identified. We found 109 such patents: in 26 of them, the inventors were exclusively Polish. Table 8 presents the ranking of the top 8 foreign grantees with Polish inventors in 2015.

Table 8. European Patent Office (EPO) – Ranking of Top 8 foreign grantees with Polish inventors in 2015.

Grantee	Country	2015
ABB Technology AG	Switzerland	12
BSH Hausgeräte GmbH	Germany	5
CCS Technology, Inc.	USA	4
Lonza Ltd.	Switzerland	4
Mentor Graphics Corporation	USA	4
Bombardier Transportation GmbH	Germany	3
General Electric Company	USA	3
Nokia Solutions and Networks Oy	Finland	3
TOTAL		**38**

The Poles invent mainly for companies, most of them from Switzerland (25.0% of patents granted between 01 January 2015 to 31 March 2016), Germany (24.0%) and the USA (19.0%).

6. The key fields of Polish inventors

The data we retrieved from the European Patent Office for 2015 in terms of technology fields where Polish inventors were involved are shown in Figure 4.

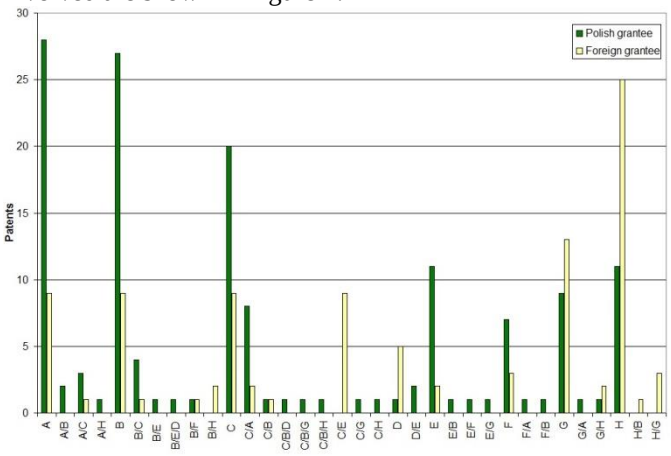


Fig. 4. European Patent Office (EPO) – Fields of technology of Polish inventors in Polish and foreign patents 2015 according to the International Patent Classification: A – Human Necessities; B – Performing Operations, Transporting; C – Chemistry, Metallurgy; D – Textiles, Paper; E – Fixed Constructions; F – Mechanical Engineering, Lighting, Heating, Weapons, Blasting; G – Physics; H – Electricity.

For Polish patent grantees, Poles invent mostly for human necessities (44 patents out of 150), performing operations / transporting (42), and chemistry / metallurgy (41). For foreign patent owners, Poles invent mostly in chemistry / metallurgy (23 patents out of 90), electricity (18) and performing operations / transporting (15).

7. Discussion

Based on the findings presented in this study we found that awareness in Poland of intellectual property and its commercial potential is unsatisfactory. The large number of "home-grown" patents with universities as leaders, and simultaneously low interest of commerce to exploit these inventions [10, 11] lead us to the conclusion that universities patent their inventions in order to improve their rating scores at the Polish Ministry of Science and Higher Education.

Despite significant changes in the university rating scheme, there is still little internal "pressure" from technical universities on their researchers to deliver research results which are commercially feasible. At the same time, elements of academia are still reluctant to come up with utility solutions at the expense of "shelf-oriented research", which may result in an invention but will not necessarily be put into practice. Furthermore, low inventive activity is driven by bureaucracy at universities, lack of practical solutions in terms of commercialising research results, and imprecise expectations of the actors in the process: technology transfer offices, researchers and companies.

Another problem, not discussed in this paper, is lack or very little knowledge of methodologies of systematic inventive problem solving (e.g. TRIZ) at Polish technical universities [5]. The teaching process at most technical universities is based on the ex-cathedra model, instead of Problem Based Learning or Learning By Doing. This leaves graduates poorly equipped to invent or innovate [4].

On the other hand, the EPO statistics are very positive for the most active Polish enterprises in terms of patents, showing their potential to grow, their developing awareness of the need for IPR protection, and the need to compete in order to develop and hold the market for their products and services.

The low number of patents granted to Polish owners by the EPO, in comparison to the total granted by the UP RP, results probably from high fees for filings and applications. Additionally, the European patent procedure is time consuming and, because of that, discouraging for applicants. Presumably, the EPO cares less for the pace of patent application processing than the applicants themselves.

8. Conclusions

The Polish patent most of their inventions in Poland, as seen in Figure 5. Although the ratio between inventions disclosed to the UP RP and the EPO has fallen gradually, the difference is still considerable: in 2008 there were 55.8 times more patents granted by the UP RP than the EPO; in 2012, 23.1 times and in 2015, 16 times. From the point of view of the EPO, enterprises are the leading Polish patent grantees, while from the point of view of the UP RP, universities. Both at national and European levels, the most active areas of Poland in terms of inventing are Mazovian, Silesian and Lesser Poland voivodeships.

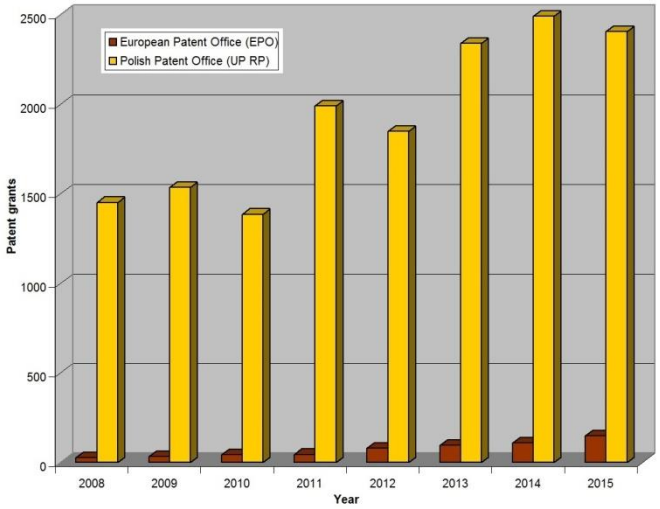


Fig. 5. Polish patents in European Patent Office (EPO) and Polish Patent Office (UP RP), 2008–2015

In the EPO, Polish patents are practically insignificant vs. other, comparable countries. Foreign applicants disclose their inventions mainly through the EPO, very rarely designating Poland as the country of patent protection. The number of patents with Polish (co)inventors is similar both when Polish and non-Polish grantees own them. The Poles invent mainly in four out of the eight fields categorised by the International Patent Classification, i.e.: A – human necessities, B – performing operations/ transporting, C – chemistry/metallurgy and H – electricity. When inventing abroad, they invent most often for enterprises in Switzerland, the USA and Germany.

Summing up, indices for Poland suggest that it might be more innovative in the future, but there are still many challenges to overcome. To build human capital capable of inventive problem solving which will be supportive to Polish enterprises making innovations, it is necessary to improve procedures, including those at universities, increase awareness among the university academics and management, but most of all improve the teaching process by introducing TRIZ to the curricula of Polish technical universities.

Poland has produced outstanding individuals: Copernicus, Skłodowska, Huber, Czochralski, Szczepanik, to name just a few. And it has many resources to start "a massive production of inventors". We hope that awareness and processes can align to carry on this tradition.

Acknowledgements

This publication is financed through a research grant from the Ministry of Science and Higher Education of Poland 4/S/ITESO/14: "Diagnostics methods and efficient operation of complex technical systems in terms of failure prevention and environmental protection".

References

[1] Altshuller G. The Innovation Algotithm. TRIZ, Systematic Innovation and Technical Creativity. Worcester: Technical Innovation Center, Inc.; 2007.
[2] Annual raports 2006-2014. Polish Patent Office.
[3] Central Statistical Office. Działalność badawcza i rozwojowa w Polsce w 2014r., Warszawa, 14.10.2015.
[4] Chybowski L, Idziaszczyk D. Czy design thinking jest przydatny w kształceniu inżynierów? (Is design thinking useful in educating engineers?). In: Milewska E, Żabińska I, editors. Systemy Wspomagania w Inżynierii Produkcji. Inżynieria Systemów Technicznych. Gliwice: P.A. NOVA; 2014. pp. 43-55.
[5]Chybowski L., Idziaszczyk D., O antropocentrycznym i technocentrycznym podejściu w procesie tworzenia innowacji (Anthropocentric and Technocentric Approach in Creating Innovation). In: Brodny J, Dziemba Ł, editors. Systemy Wspomagania w Inżynierii Produkcji. Inżynieria Systemów Technicznych z. 2(11). Gliwice: P.A. NOVA; 2015. pp. 51-63.
[6] EPO statistics for Poland. Website: https://www.epo.org/about-us/annual-reports-statistics/statistics.html [accessed: 22 June 2016].
[7] European Patent Bulletins nos.1502-1553, 2015.
[8] Eurostat News Release, 209/2015, 30 November 2015.
[9] Higher Education Institutions and their Finances in 2014, Central Statistical Office, Warsaw 2015.
[10] Narodowy Bank Polski. Potencjał innowacyjny gospodarki: uwarunkowania, determinanty, perspektywy. (Central Bank of the Republic of Poland, Innovative potential of Polish economy: conditions, determinants, perspectives) Warszawa, May 2016.
[11] Orłowski WM. Komercjalizacja badań naukowych w Polsce. Bariery i możliwości ich przełamania (Commercialisation of research results in Poland. Barriers and opportunities). Warszawa: PwC; 2013.
[12] Polish Patent Office Quarterly. Issue 1/27/2016. Polish Patent Office, 2016.
[13] Ranking największych gospodarek w Unii Europejskiej. Website: http://euro-dane.com.pl/wydarzenia-gospodarcze-428 [accessed: 22 June 2016]

Opportunities for integrating TRIZ and systematic innovation tools into large scale Agile software development

Teemu Toivonen
Nitor Delta, Finland
E-mail: teemu.toivonen@gmail.com

Abstract

Many organizations (private and public) are scaling their software development in order to achieve the required speed and scope to digitalize their current business and utilize opportunities for creating new digital business. Effective and efficient scaling of software development is not an easy problem, although several approaches have emerged in order to solve this problem. Some of these methodologies have experienced reasonable success, one in particular simply known as Scaled Agile Framework (SAFe) is one of the more popular.
SAFe is a holistic framework for Agile software development. The version 3.0 of the SAFe delivers guidance on how to organize and run software development across three layers: 1) portfolio level; 2) program level; 3) team level. The framework gives guidance in terms of principles, roles, deliverables and concrete ways of working. Version 4.0 also adds an optional value stream layer.
The article will cover all layers in terms of their key activities (functions) and highlight key problems using real world examples. Integrating TRIZ/SI tools to the SAFe framework will be addressed from four different perspectives: 1) opportunities to use TRIZ/SI tools to create a focus on more breakthrough innovations as opposed to incremental innovation; 2) addressing key problems in existing SAFe practices with TRIZ/SI tools; 3) using TRIZ/SI tools to enhance the existing SAFe approach; 4) easy to approach examples of using TRIZ/SI tools from real world scenarios.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: TRIZ; Systematic innovation; Software development; Agile; Scaled Agile Framework

1. Introduction to SAFe and background information

Nomenclature

TRIZ	Theory of inventive problem solving
SAFe	Scaled Agile Framework
SI	Systematic innovation

The SAFe framework is a comprehensive knowledge base for doing large scale agile software development. It gives guidance for team level (how should Agile teams work), program level (how should planning, coordination and integration be done across teams) and portfolio level (selection and analyses of initiatives, setting high level goals, linking strategy to development work, and program level funding decisions).

Version 1.0 was published in 2011. It is based on extensive experiences gathered from many companies and sources. The current version of the framework is 4.0 (published in January 2016). The 4.0 version is fully backwards compatible with the widely used 3.0 version. The main differences between the 3.0 and 4.0 version s is that the 4.0 version adds an optional value stream layer for scaling software development even more than 3.0 three layered approach [1].

The SAFe content model also has three linked layers: 1) on the Portfolio Epics are large initiatives that can span across multiple programs, 2) on the Program layer content is described as features that can be fully completed within the 8-12 week product increment cycle, 3) on the Team layer content is described as user stories that can fully completed in two week sprints.

The reference documentation for the framework is freely available on the SAFe website [2]. This article will focus on the three original layers of SAFe (Portfolio, Program and Team).

The SAFe framework is widely adopted in the software industry with over 60 % of Fortune 100 U.S. companies having certified SAFe practitioners and consultants on site. The publicly available SAFe case studies report benefits ranging from [1]: 20 – 50 % increase in productivity, 50 % + increases in quality, 30 – 75 % faster time to market and measurable increases in employee engagement.

Innovations is also an integral part of SAFE and one of the core pillars of the SAFe lean house, which is advocated as part of the Lean Agile mindset. Core tenants of SAFe's approach to innovation are [3]:

Table 1. SAFe approach to innovation

Producers innovate, customer validate	There is a strong focus in creating empirical feedback loops based on the real customer's experience.
Get out of the office	A deep understanding of customer context and problems, which is need for innovation, can only be gained by doing field work
Provide time and space for creativity	Innovation requires time and resources on all levels of the organization. An example of this is reserving capacity on the team and program level for innovation activities in the last sprint of the product increment.
Apply innovation accounting	Non-financial metrics are used to objectively evaluate success.
Pivot without mercy	Once facts show that a hypothesis is not supported by reality pivot quickly to the next hypotheses.

In addition to the explicitly stated principles, SAFe has many ideas integrated into its practices that support innovation. The author wishes to highlight the following based on his personal experiences:

Table 2. Additional SAFe innovation elements

Short feedback loops	Creating short feedback loops by emphasizing small batch sizes and limiting work in progress on all levels of the SAFe model creates an opportunity for fast learning based on real experiences.
Collaboration	Collaboration is extensively emphasized in many SAFe practices. By including many different roles and perspectives in planning and design the likelihood of innovative solutions is increased.
Top down and bottom up	The SAFe approach advocates top down alignment on business goals, but the solution details are iteratively designed by adding more detail on each level, which leaves room for innovation on all organizational levels. The model also explicitly encourages collecting epic and feature ideas from the team level.
Ownership and commitment	Each role owns their own practices and is encouraged to continually improve them as part of the SAFe approach. This creates continuous innovation in the ways of working in all aspects of large scale software development.

While the SAFe framework strongly supports innovation, that does not mean it is without it's pitfalls in this regard. SAFe has a strong process focus and offers a lot of guidance on how ideas are collected, processed, document and validated with customers. It does not however give a lot of guidance on how to systematically support ideation and step change oriented problem solving. It also emphasizes the need for a vision and goals, but gives very limited guidance on how to create the content for those visions and goals. One could make the argument, that SAFe offers a good model for collecting and testing ideas, but is agnostic about how to come up those ideas.

On the other hand TRIZ offers effective approaches to all three of these gaps:

Table 3. SAFe innovation "gaps" and TRIZ tools

Creating innovative solutions	Examples of TRIZ techniques: Inventive principles, trends, perception mapping, contradiction analyses.
Step change problem solving	Examples of TRIZ techniques: Inventive principles, contradiction analyses, standard solutions, psychological inertial tools
Vision and goal setting	Examples of TRIZ techniques: ideal final result, contradiction visualization, trend evolution potential mapping, S-curve analyses

Hence integrating TRIZ tools into the SAFe framework offers significant potential to enhance and extend SAFe's current approach to innovation. TRIZ can also gain from the wide adaptation of SAFe, as it offers a vessel to familiarize many organizations with TRIZ ideas and tools.

2. The Portfolio level

The portfolio represents the highest abstraction level in the SAFe framework. The portfolio level is the basic construct for organizing the enterprise around the flow of value via one (or several) value streams. It encapsulates all the activities (processes, roles, etc.) required to build the solutions it needs to meet strategic objectives. The portfolio level also provides budgeting and governance for the overall activities [4].

The portfolio level key concepts in SAFe are [4]:

- **Connection to enterprise -** the portfolio provides a bidirectional connection with the enterprises by setting the portfolio goals collaboratively and providing constant feedback to the enterprise through KPI's and qualitative feedback.
- **Program portfolio management** – the program portfolio management is the highest fiduciary and content authority within the SAFe framework. They are responsible for portfolio level governance and funding decisions for the values streams or release trains**.**

- **Managing the flow of portfolio epics** – discovering, defining and managing major initiatives. These initiatives are defined as "business epics" and managed with a Portfolio Kanban process.

The author has identified the following functions provided by the portfolio level in experience applying it into practice (mostly version 3.0 of SAFe):

Table 4. SAFe portfolio level functions

Setting high level goals	The business goals of the portfolio are communicate with a portfolio level vision and strategic themes (containing KPI's). SAFe promotes the idea, that they are based on company strategy. In practice often significant amount of interpretation or even innovation is required to come up with the right goals.
Collecting and creating high level solution ideas	High level solution ideas are collected (and/or created in workshops) with key stakeholders. The ideas are documented as "epic value statements", which is a document template designed to support customer focused thinking.
Analyzing high level solution concepts	Analyzing solutions concepts is done iteratively in the SAFe Portfolio Kanban process. The solution concepts are lightly analyzed first in the "review phase" and the ones that are prioritized after this phase are more thoroughly analyzed in the "analyze phase". As part of the analyses work also portfolio level architecture work is done to identify possibly needed enabler solutions for the actual business solutions.
Prioritizing high level solutions concepts (and go/no decisions)	Prioritization of solutions concepts is done iteratively in the SAFe Portfolio Kanban process. The solution concepts are prioritized again after each phase of the Portfolio Kanban process and advance to the next phase based on a "pull" principle ones there is free capacity. Some of the solution concepts are also dropped based on analyses.
Managing time to market	The portfolio Kanban process optimizes flow on the portfolio level by limiting the amount of "work in progress". This has the consequence of reducing through put time for an epic and the effect is amplified by a strong focus on minimum viable product thinking in general.
Benefits validation and communication	The portfolio management is constantly monitoring the results of the development work based on KPI's and qualitative measures. This provides feedback for future development work, strategy and also communicates the achievements of the portfolio. Accepting epics as done is also a portfolio level activity and some companies have added a separate benefits validation phase to the Portfolio Kanban process.
Resource and funding decisions	High level resource allocation and funding decision are done on the portfolio level. These decisions are based on strategy, available funding and in general the needs of the enterprise. These decisions create the boundaries within the value stream, release train and team level activities function in.
Continuous Learning	Learning based on feedback from program level and stakeholders and use the learning adjust portfolio goals (long term adjustments) ja epics (short term adjustments).

2.1. Opportunities to use TRIZ/SI tools to create a focus on more breakthrough innovations

On the Portfolio level, two key TRIZ concepts can be used, to transition the focus from improving the current condition incrementally to systematically driving radical innovation: 1) predicting the future, 2)Framing key problems as contradictions

TRIZ offers many tools for understanding and predicting the future. Instead of only relying on existing strategy and vision, understanding the future can be a key portfolio level activity. Identifying the ideal final result for the customer and stepping backwards until a meaningful portfolio level vision is reached, or predicting the likely areas were a breakthrough innovation can occur with trend analyses, can be a powerful addition to the SAFe framework to drive true step change innovation.

Framing key problems as contradictions is a powerful concept for changing the mindset from traditional optimization thinking. Framing contradictions on the portfolio level also creates clear demand for tools that help create solutions to those contradictions in other areas of the SAFe framework.

2.2. Addressing key problems in existing SAFe practices with TRIZ/SI tools

Based on the author's experience there are two areas were SAFe does not provide enough support on the portfolio level:

- How to define a clear and compelling vision (and themes)
- How to generate high quality innovative content for the Portfolio level (Epics)

TRIZ can help address the first issue by documenting Stakeholder ideal final result definition [5, pages 141-144] or contradiction conversion template [6, pages 52-54]. These two TRIZ tools will help create clear and compelling high level goals and will also support using other TRIZ tools in other areas of the SAFe framework. As discussed in the previous chapter this will also support breakthrough innovative thinking instead traditional optimization thinking.

Although there rarely is a shortage for Portfolio level content (epics), usually on the contrary, there is never enough high quality ideas. This is another area were TRIZ can contribute significantly. Classical TRIZ idea generation tools like inventive principles [5, pages 184 – 96] and nonlinear trends [5, pages 329-338] can used to generate a large number of ideas, which have a good change at hitting the right area from an innovation point of view. These tools become easier to apply if they are used in conjunction to defining the portfolio vision and themes as contradictions.

2.3. Using TRIZ/SI tools to enhance the existing SAFe approach

There are numerous ways of enhancing the existing SAFe functionality with TRIZ tools. TRIZ tools can integrated into all of existing useful functions of the Porftolio level. This article will not attempt to exhaust the possibilities, but rather give a few examples:

- TRIZ psychological inertia tools like nine windows [5, pages 63 – 80] can make a good addition the analyses of high level solution concepts (epics). Often people get trapped into a traditional or known approach and tool like nine windows can help identify alternative (perhaps non software) approaches to achieving the desired business outcome.
- SAFe uses a Portfolio Kanban system to manage the time to market by limiting the amount of work in progress. This is an effective approach, but sometimes there are other creative solutions to quickly getting a new idea implemented. The problem can be modeled as a conflict between speed and resources and inventive principles [5, pages 184 – 96] can used to create solution ideas.
- Decisions on how to allocate funds to the program level are done on Portfolio level based on business needs. Resource analyses [5, 395 – 411] can be used to supplement this process and identify free and/or unused development resources to grow the amount of total resources that are available.

2.4. Example

Setting high aiming goals that create a clear sense of direction is one of the most important portfolio level activities. In SAFe this is done through the portfolio vision and themes. Ideally this vision is known and understood by everyone in the organization and it guides everyday action.

Often the portfolio vision and themes fails to though this in practice, either because the vision is too rounded, or because the vision encourages only one aspect at the cost of others (digitalize business) without framing the breakthrough contradiction that needs to be solved.

TRIZ can help with this by framing the portfolio vision as a technical conflict and contradiction using the contradiction definition template [6, pages 52-54]. This templates visualizes the goal in a way that encourages innovative non-tradeoff thinking and gives a clear sense of direction. TRIZ contradiction solving tools can then be applied to create portfolio level development ideas (epics).

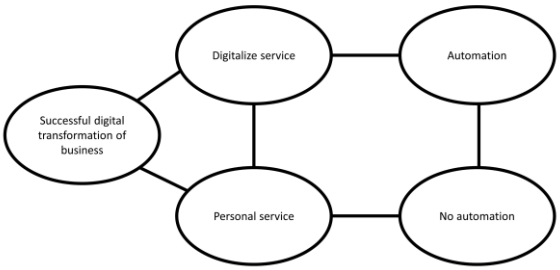


Fig. 1 The digitalization contradiction.

3. The Program level

The SAFe program level contains the necessary teams and program level roles to develop the solutions that the release train is responsible for. Agile release trains are virtual organizations that cut across organizational boundaries to deliver value according to SAFe Lean-Agile principles. The size of a release train (Program level unit) is between 50 and 125 people. The release trains plan their work in 8-12 product increments in a collaborative way. The work of the different teams are integrated (at a minimum) every two weeks [7].

The author has identified the following functions provided by the program level in his experience applying it into practice (mostly version 3.0 of SAFe):

Table 5. SAFe program level functions

Feature level road mapping and prioritization	Prioritizing the features on the Program backlog and creating a development roadmap for 2-4 product increment cycles (with increasing uncertainty). Sometimes a vision is used together with the roadmap.
Feature level content creation	Creating feature level content based on epics and other development ideas. A feature is a piece of content that can be developed during the product increment cycle (8-12 weeks).
Architecture and user experience design	Design of high level architecture and user experience, which creates the boundaries within which the actual development work is done.
Development planning	Collaborative planning on what the teams can commit to doing in the product increment cycle (8-12 weeks) and making sure all teams are aligned and dependencies are identified.
Development coordination	Coordination of development activities during the product increment cycle (8-12 weeks). Dependency management, integrations, cross team issues, etc.
Release management	Collaborative decision making related to releases (time, scope, acceptable risks).
Continuous learning	Learning based on experience and reflection and making adjustments based on that learning.
Stakeholder management	Ensuring alignment with active stakeholder communication (roadmaps, product increment plans, demos).

3.1. Opportunities to use TRIZ/SI tools to create a focus on more breakthrough innovations

The two areas were TRIZ can make a big contribution on the SAFe program level are:

- Systematically looking for solutions from different perspectives (including non-software)
- Contradiction and contradiction resolution thinking

One thing SAFe does really well is incorporate high level user experience and architecture planning on the program level without falling into the trap of excessive upfront planning. Still, we are all confined to some extent, to our professional identities and this can lead to looking for solutions from only certain perspectives. Adding TRIZ psychological inertia and benchmarking tools (knowledge/effects) helps create a systematic way of looking for creative solutions from many perspectives.

Since most people working with software development have very analytical training making trade-off decisions can become second nature. By integrating contradiction identification and resolution principles into SAFe we can try to change the mind-set towards creative breakthrough innovation.

3.2. Opportunities Addressing key problems in existing SAFe practices with TRIZ/SI tools

Based on the author's experience there are two important areas in Program level were TRIZ can used to fill in the gaps of the current SAFe approach: 1) a systematic approach to generate alternative solution and design approaches, 2) creative problem solving for key problems

Psychological inertia tools like nine windows [5, pages 63 – 80] and systematically searching for alternative ways of achieving a benefit (function) with knowledge database searches [5, pages 413 - 424] can be used to create a new program level activity were alternative solution approaches (outside software development) researched. The idea is to identify possibilities when instead of doing software development the business outcome can be achieved with for example process or communication changes. This frees the limited software development capacity to those features that cannot be achieved by alternative means.

TRIZ offers an effective approach to solving difficult problems in creative ways by framing problems as contradictions and offering effective tools for solving those contradictions. The basic contradiction framing and solution approach is relatively easy to teach (though hard to master) and can be integrated into many areas of Program level SAFe:

- Solving key problems in product increment planning
- Solving key problems in design (architecture and user experience)
- Solving key problems that occur during the product increment development phase

3.3. Using TRIZ/SI tools to enhance the existing SAFe approach

Just like in the Portfolio level there are numerous ways of integrating TRIZ tools into existing SAFe practices and instead of aiming for a comprehensive list this article will just give a few examples:

- SAFe advocates a Lean approach to architecture and gives good guidance on how to achieve it. The TRIZ trimming tool [5, pages 437 – 452] is a good fit to designing an even more Lean architecture and can be used to systematically remove unnecessary elements.
- Blocking issues (impediments) are raised to the program level twice a week in Scrum of Scrums coordination meetings. Conflict resolution strategies (T2, pages 56-57) can used as an easy to integrate tool come up with alternative solution approaches.
- At the end of the product increment cycle (8 – 12) weeks there is a program level retrospective where key problems are identified and solutions generated. The program level issues can often be quite complex, so perception mapping [5, pages 149 – 167] be used to understand relationships of different perceptions surrounding the issue and identifying good candidates for intervention.

3.4. Example

Product increment planning is one of the best and most important SAFe practices. It is when everyone who is participating with the development work comes together for a 2 day planning event where the teams commit to a goal (and supporting plans) for the 8-12 weeks. A common issue in product increment planning is that there is a conflict between how many features the teams can commit to doing in the time box and security (or other quality) requirements. Often the outcome is making acceptable tradeoff between the two conflicting needs.

An alternative approach is to model the situation as a contradiction of speed against security and look up the corresponding inventive principles [8, page 399] which are 24, 10, 28, 1, 19 and use them to create ideas that allow the more features without jeopardizing security and incorporate those ideas into the product increment plan.

4. The Team level

Agile teams are the foundational unit that does to work in the SAFe model. Agile teams define, developing, testing and delivering working solutions. The cycle of work for Agile teams is the 2 week sprint cycle which starts with sprint planning and ends with demo and retrospective. The teams follow Agile quality practices and integrate regularly with other teams [9].

The author has identified the following functions provided by the team level:

Table 5. SAFe Team level functions

User story level content creation and prioritization	Creating story level content (can be done within 2 week sprints) and prioritizing team backlog based on program level plan. Sometimes a vision is used together with the roadmap.
Planning	Team level planning (2 week sprints) for development work.
Development and testing	Development and testing work for planned user stories. This work includes detailed level architecture and design work within the guidance of the program level.
Team level coordination	Coordination of development work within team and direct connections to other teams.
Continuous learning	Learning based on experience and reflection and making adjustments based on that learning.
Stakeholder management	Ensuring alignment with active stakeholder communication (sprint plan and demos).

4.1. Opportunities to use TRIZ/SI tools to create a focus on more breakthrough innovations

The main opportunities for creating a more breakthrough innovation focus on team level are the same as on the Program level, although the scale to which they are applied to is smaller.

Generating alternative solution approaches that go beyond the realm of traditional software development and utilizing contradiction definition and resolution techniques are areas which differentiate teams from average or even very good software development teams.

4.2. Addressing key problems in existing SAFe practices with TRIZ/SI tools

Based on the author's experience there are two important areas in Team level were TRIZ can be utilized to fill the current gaps in SAF are similar than on the program level, but on a smaller scale: 1) finding alternative ways of achieving the intent of user stories (team level content that can be implemented within a two week sprint) using for example psychological inertial tools, 2) creative problem solving for key problems by framing them as contradictions and using TRIZ contradiction resolution tools to generate solutions.

4.3. Using TRIZ/SI tools to enhance the existing SAFe approach

Select inventive principles as part of sprint planning to get more stuff in (solve contradiction of limited resources and a lot of content):

- Using the 12 contradiction resolutions strategies (6, pages 56 - 57) to generate solution to blocking issues (impediments) that are raised on the team's daily coordination meeting (daily standup)
- Solving key issues in sprint planning by framing them as contradictions and using inventive principles to generate solutions.
- Generating supplementary quality practices for the standard Agile quality practices based on modelling the issue as a contradiction and using inventive principles to generate solutions.

4.4. Example

The teams have a retrospective (function: continuous learning) on a regular cadence every two weeks to reflect on their situation and to identify improvement actions. This is a really good and core practice in SAFe, but after a while the retrospectives can become a little bit stale and sometimes the teams stop doing them all together.

A good way to spice retrospectives, and come up with better improvement actions, is to introduce TRIZ tools to the retrospectives. While there is many ways of doing this, perhaps the most simple one, is to have the teams choose a problem that they have struggled to solve earlier and use the 12 conflict resolution strategies (6, pages 56-57) to come up new ideas on how to address the issue.

The workflow of facilitation can simple and done within a 90 minute time slot: 1), Identify many potential hard solve issues, 2) select one hard to solve issue by voting, 3) generate many potential solution ideas by using the 12 conflict resolution strategies, 4) select one idea by voting that the team will commit to implementing

5. Conclusions and next steps

This article outlined on a high level how TRIZ can be integrated into the Scaled Agile Framework to drive innovation and support existing practices. Due to this the amount of details that was covered in this article was limited. Hopefully it will serve as a starting point for more experimentation and research how TRIZ and SAFe can together drive the digitalization needs of modern businesses'. The author plans to right a more detailed paper outlining the specifics on how TRIZ can Agile Portfolio management can together form a holistic, innovative and Agile Portfolio management model.

A possible way forward is to propose some TRIZ concepts, tools and templates to be included on a future release of the Scaled Agile Framework. This would open TRIZ for a wider audience in the software development scene and enarmor SAFe with a mature innovation approach.

References

[1] Scaled Agile Academy, About SAFe, http://www.scaledagileframework.com/about/, 27-6-2016
[2] Scaled Agile Academy, SAFe reference documentation, http://www.scaledagileframework.com/, 27-6-2016
[3] Scaled Agile Academy, Lean Agile mindset, http://scaledagileframework.com/lean-agile-mindset, /27-6-2016
[4] Scaled Agile Academy, Portfolio level, http://scaledagileframework.com/portfolio-level/, 27-6-2016
[5] Darrell Mann, Hands on systematic innovation for business and management, IFR Press;2007.
[6] Darrel Mann, Innovation Capability Maturity Model: An Introduction, IFR Press; 2012
[7] Scaled Agile Academy, Program level, http://scaledagileframework.com/program-level/, 27-6-2016
[8] Darrel Mann, Systematic (software) innovation, IFR Press;2008
[9] Scaled Agile Academy, Team level, http://www.scaledagileframework.com/team-level/, 27-6-2016

Optimizing motor performance by using TRIZ methodology

Matej Hohnjec[a,*], Dušan Gošnik[a], David Koblar[b]

[a]3ZEN d.o.o., Tacenska 125B, Ljubljana 1000, Slovenia
[b]Domel d.o.o., Otoki 21, Železniki 4228, Slovenia

* Corresponding author. Tel.: +386-31-663-110. *E-mail address:* matej.hohnjec@3zen.si

Abstract

This paper presents example of TRIZ methodology use for optimization of motor performance. The goal was to reduce the noise level and at the same time maintain the efficiency of vacuum cleaner motor. Technical contradiction and contradiction matrix was used for generation of ideas. Solutions were evaluated based on feasibility and effect on result. Prototypes of solutions with highest grades were produced and further sound power levels and air performances were measured. From measured values optimal solution with the most favorable ratio between noise reduction and loss of efficiency was chosen.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: motor; noise; efficiency; contradiction; TRIZ

1. Problem description

Motor is one of the key components of vacuum cleaner. It generates noise and at the same time has significant impact on the efficiency and consequently energy label. Our task was to reduce noise of the vacuum cleaner motor and at the same time improve (or not decrease) its efficiency. Our main limitation was that there were no changes possible on the motor. So, main idea was to build the motor inside the additional housing (capsule). The main function of the capsule was to improve the flow of the air and decrease noise emission in the environment and to eventually improve (or not decrease) energy label of the vacuum cleaner.

Fig. 1. Vacuum cleaner motor and capsule for bigger version

2. Idea generation

For idea generation for solution of this problem we established multifunctional team of experts which included mechanical and electrical engineers, physicians and TRIZ experts. Based on the problem description we have defined technical contradiction. Table 1.

Table 1. Defined technical contradiction for motor.

Form	Technical contradiction 1	Technical contradiction 2
IF	the path of airflow is long	the path of airflow is short
THEN	we have lower noise	efficiency is better
BUT	efficiency is worse	we have more noise

This contradiction was defined based on the fact that if we ad capsule, we can modify airflow path and at the same time with the longer path we decrease efficiency. Based on the contradiction matrix Table 2 shows us which parameters were detected to be improved and which parameters were detected to be worse.

Table 2. Detected improved and worsened technical parameter. [1]

Improved parameter	Worsened parameter
22 - Loss of energy	19 – Use of energy of moving objects
31 – Object generated harmful factors	21 - Power
9 - Speed	22 - Loss of energy
21 - Power	39 - Productivity

Table 3 shows us which inventive principle (IP) was detected to solving this problem.

Table 3. Idea generation. [1]

Inventive principle	Our idea for solution
IP 22 - Blessing in disguise	Modifying noise frequency, additional resonator, modified air pipe at the exit holes in the capsule
IP 39 – Inert atmosphere	Vacuum in the capsule, gel on the bottom
IP 28 - Mechanics substitution	Ionization, use of magnetic field
IP 3 - Local quality	Locally two walls on the capsule, foam
IP 29 - Pneumatics and hydraulics	Additional air bag
IP 10 - Preliminary action	Isolation around the capsule
…	…

Based on the all generated ideas (27) team has evaluated each one of them considering feasibility and impact on the result. These solutions were tested and noise/efficiency measurements were performed. We have measured sound power level and air performance. Next change of sound power level (ΔLw), change of efficiency (Δη); and average grade (ΔLw+Δη) were calculated. During measurements additional solutions were made with adding, removing, changing foam etc. All together measurements were made on 11 prototypes. In Figure 2 and 3 measurements are presented. On graphs difference in sound power level (blue), difference in efficiency (orange) and the average grade (grey) are presented. Fig. 2 shows results at higher airflows (orifice D23 mm simulates empty dust bag in vacuum cleaner).

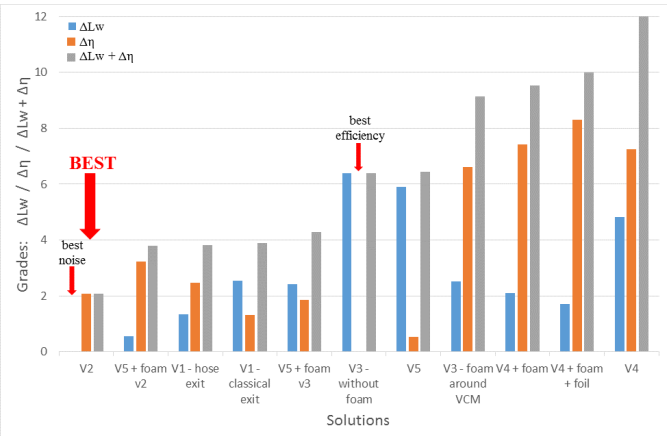


Fig. 2. Results for different solutions at higher airflow (D23)

In Figure 3 results at lower airflows are presented (orifice D16 mm simulates full dust bag in vacuum cleaner).

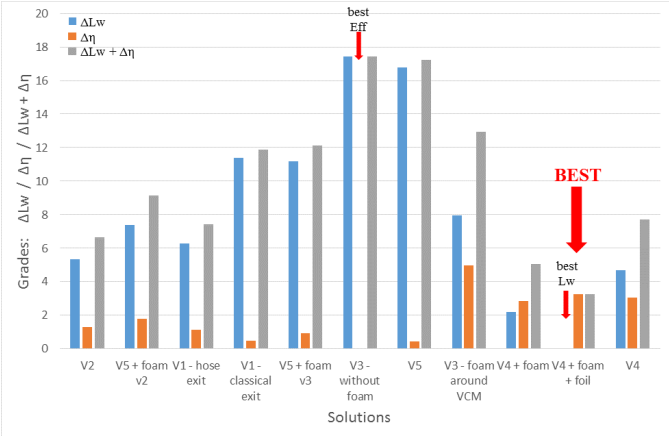


Fig. 3. Results for different solutions at lower airflow (D16)

3. Conclusion

This paper presents an example how TRIZ methodology was used on vacuum cleaner motor. With TRIZ we were systematically guided to start thinking about other possible solutions. This way 27 new solutions to reduce noise of vacuum cleaner motor were obtained. Best five solutions were manufactured and measured. As a result, we obtained one best solution for high airflow and one best solution for low airflow.

For higher airflows the best solution was V2 (capsule made of isolation material). This solution was also the solution with the lower sound power level. Following the best solution are three different solutions that are very close to each other. The solution with the highest efficiency was V3 (capsules with the concentric resonator + foam) where foam was taken out of the assembly.

For lower airflows the best solution was V4 with additional foam around the circumference and the foam was covered with plastic foil. This solution was also the solution with the lowest sound power level. The solution with the highest efficiency was again V3 where foam was taken out from the assembly.

Further solutions have to be judged regarding the price of material and technology to manufacture each of the solutions.

References

[1] Altshuller G. 40 Principles. Extended Edition: TRIZ Keys to Technical Innovation, Technical Innovation Center, Worcester, USA, 2007

R&D in Poland: is the country close to a knowledge-driven economy?

Dorota Chybowska[a], Leszek Chybowski[b,*]

[a]*Maritime University of Szczecin, Technology Transfer Office, 1-2 Waly Chrobrego St., 70-500 Szczecin, Poland*
[b]*Maritime University of Szczecin, Faculty of Marine Engineering, 1-2 Waly Chrobrego St., 70-500 Szczecin, Poland*

* Corresponding author. Tel.: +48-91-480-94-12; fax: +48-91-480-95-75. *E-mail address:* l.chybowski@am.szczecin.pl

Abstract

Poland has a strong ambition to evolve rapidly into a knowledge-driven economy. Since 2004, it has been the largest beneficiary of European Union cohesion policy funds among all member states. Between 2007 and 2013, Poland was allocated approximately EUR 67 billion, whereas for 2014–2020 the EU budget earmarked EUR 82.5 billion for Polish cohesion policy. This means that in the coming years, Poland's R&D intensity will grow. But the question remains: is 27 years of free market economy enough to enable a country's economy to become knowledge-based? This paper offers an analysis of Polish R&D expenditures and investments in terms of their sources (business, government or higher education sectors), types (European Union or state aid) and areas of support (infrastructure, education or innovation). It also characterises the Polish R&D market with its strengths and weaknesses. Then, it examines the process of technology transfer in Poland, comparing it to best practice. Finally, the paper lays out the barriers to effective commercialisation that need to be overcome, and attempts to answer the question raised in its title.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: commercialisation; Poland; R&D market; knowledge-driven economy; technology transfer

1. Introduction

While the world was undergoing technological revolutions, Poland was fighting for freedom: for the right of its people to live with dignity, express their thoughts, develop and contact countries outside the Eastern Bloc. In 1970 IBM filed a patent application for a floppy disc [9]; in Poland in December of the same year the militia and the army were breaking the strikes of Polish workers. In 1981 the first space-rated orbiter Columbia was built in the USA [2], while in Poland martial law was enforced. In 1989 the Polish people were the first nation in the world to overthrow communist rule.

In fact, the 20th century was littered with historical events that directly impacted the Polish economy. Poland was able to resurface after the destruction of the First World War, and during the inter-war period was among the top 10 patent applicants in Europe. The Second World War interrupted its development, but despite what then followed, it would not be fair to say that between 1945 and 1989 Poland performed poorly, did not invent or make developments [12]. In this period, for instance, the Melex electric golf cart left the factory (1971) to become popular among players around the globe [14], and a team of scientists created the K-202 computer (1970–73) [11]. However, the majority of inventions and cutting-edge ideas were never introduced in Poland because of the political system and budget deficits, or were introduced elsewhere by Polish inventors for the benefit of other, already blooming economies. The route to a knowledge-driven economy was prolonged for former Eastern Bloc countries, Poland included, as shown by patent statistics for the last decade [20].

The year 2016 is the 27th year of the free market economy in Poland. In 2004 Poland became a member of the European Union and the greatest beneficiary of its structural funds: between 2007 and 2013 Poland was allocated approximately EUR 67 billion whereas for 2014–2020 the EU budget earmarked EUR 82.5 billion for its cohesion policy.

A standard definition of a knowledge-driven economy and metrics to gauge the dependence of societies on knowledge production have still been agreed [18]. Different measures used for the same performance indicators and having different

weights can result in many different rankings [3, 7]. It is therefore problematic to refer to these measures and to attempt to determine the position of knowledge for Polish economy in 2016 on this basis. However, there is the Innovation Union Scoreboard, an instrument of the European Commission to assess the innovation performance of the EU Member States; this is the best alternative available at present.

Figure 1 presents the Summary Innovation Index for Poland for the period 2007–2014. Despite the EU allocations, Poland has still performed significantly below the EU-28 average although it has shown a minimal upward trend (in 2007 the SII for Poland was 0.27, while in 2014 it was 0.313).

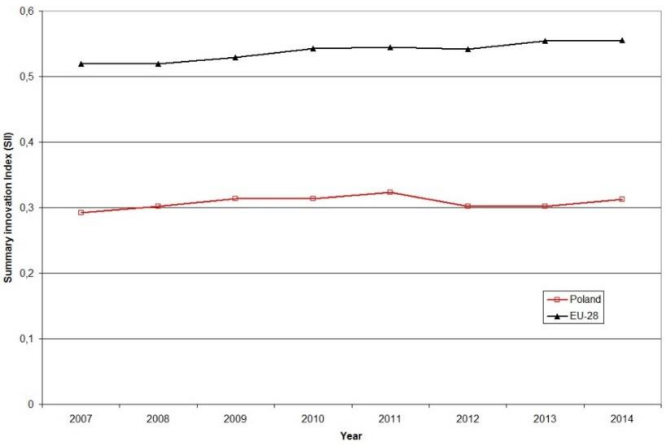


Fig. 1. Summary Innovation Index (SII) time series for Poland and EU-28 according to the Innovation Union Scoreboard 2015 methodology (Source: Authors' analysis based on [10]).

Figure 2, taken from [23] and prepared as a result of former research conducted by [8, 17, 21], illustrates key factors of different economic models. Based on this analysis, in order to rely on knowledge as its main asset and avoid the middle income trap, the Polish economy must be in possession of domestic knowledge resources [4], its own, developed, R&D facilities and technologies and products able to enter many markets.

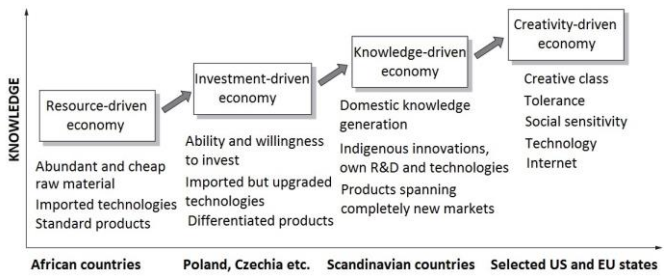


Fig. 2. Key factors of economic development [23].

In this paper, we provide an overview of the Polish R&D market; we describe the expenses and investments incurred by different sectors for R&D in recent years; we make an attempt to identify barriers to effective commercialisation of research results by presenting current stages of R&D projects in Poland; and we outline the EU structural funds and Polish funding schemes for the growth of Polish entrepreneurs' innovation and commercialisation of research results. We also search for the main causes of Poland's unsatisfactory performance in innovation.

2. The Polish R&D market

The Polish economy has strong GDP growth in relation to the EU average [15]. Polish R&D intensities grew from 0.56 GDP (EUR 1,139 M) in 2004 to 0.94 GDP (EUR 3,864 M) in 2014 [1]. Over the same period, the level of interest of the commercial sector in innovation and commercialising research results has been very low [15]: private sector R&D spend levels are several times lower than expected in terms of GDP growth (in [15] the cash flow for research from the private sector to universities and research institutes amounted to only 0.03% of GDP).

Supported by available reports [1] we contend that in Poland the governmental sector still has the largest share in the R&D financing structure: in 2014 its share amounted to 45.2%. The private sector's share rose up to 39.0% (by 14.6 percentage points in comparison to 2010). The research (educational) sector has invested the least in R&D (2.2%) [1]. As for internal R&D expenses by sectors, the private sector spends most – 47.0% of turnover, followed by the research sector (29.0%) and governmental (24.0%). There were 153,500 R&D personnel in 2014 [1]. For comparison, in the same year, there were 1,469,386 Polish university graduates.

Polish enterprises, on the other hand, are more inclined to purchase ready-made technologies, mainly abroad, choosing to compete through low labour costs.

SMEs comprise 99.8% of all Polish enterprises and employ 2/3 of the labour force. Over 45.0% of them belong to the service sector while 30.0% are in wholesale and retail trades [24]. The structure of the Polish market is significant with reference to the EU co-funding streams, both in 2007–2013 and 2014–2020, summarised in Table 1 and Table 2 respectivly.

In the period 2007–2013 (Table 1) most of the EU support was earmarked for infrastructure and environment, while in 2014–2020 (Table 2) Polish regions (voivodeships) will benefit from the greatest allocations, under the condition that they have identified and will strengthen their own key sectors of economy, the so called "smart specialisations". Poland's own contribution to this scheme equals 15%.

In terms of the development of the Polish R&D market through EU co-funding schemes, between 2007–2013 infrastructure investments had the greatest share, and the research sector (universities, research institutes) was their greatest beneficiary after enterprises,. The period 2014–2020 shifts from this model, changing the rules of distribution. In a nutshell, enterprises become the focal point, but they are obliged to consume the financial support in order to innovate and introduce new products and services to the market. It is noteworthy that the support level amounts to 50.0% on average, meaning that enterprises must invest themselves. For comparison, in 2007–2013 the co-funding rates for enterprises amounted to 80.0% EU on average. The financial perspective for 2014–2020 introduced a change for the research sector – it became a subcontractor and provider of (technological) solutions. Infrastructure investments are directed – i.e. enterprises build their own R&D facilities while universities

(re-)build their R&D facilities for the benefit of enterprises (or for their own benefit only if they are qualified for the Polish Roadmap for Research Infrastructures: to enter the list, universities must create consortia with others around given scientific areas which they are obliged to develop also by means of the EU structural funds to offer specialised services).

Table 1. Polish programmes co-funded by the European Union 2007–2013 (Source: Authors' analysis)

Financial Perspective 2007–2013		
Programme	**Budget in billion EUR**	**Purpose**
Operational Programme Innovative Economy (PO IG)	8.7	• Innovations • New technologies • Research
Operational Programme Infrastructure and Environment (PO IiŚ)	28.3	• Environmentally friendly economy and sustainable consumption of natural resources
Operational Programme Human Capital (PO KL)	10	• Employment increase • Social integration increase • Stimulating entrepreneurship • Education • Increasing the effectiveness of administration
Operational Programme Development of Eastern Poland (PO PW)	2.4	• Support for universities and science and technology parks • Providing more efficient public transport • Broadband Internet access • Cycle lanes
Regional Operational Programmes (RPO)	17.3	• Social and economic development of Polish regions
Technical Assistance	0.5	• Building the potential of public institutions distributing EU funds
Total	**67.2**	

Pressure on the development of key Polish sectors through the EU co-funding schemes in the period 2014–2020 is visible at three levels. The first level are regions (voivodeships) which, following Table 2, distribute the funds to support their key sectors. The second, national, level reflects the sectors of the Polish economy from the point of view of global competition. The third level, intersectoral, supports key sectors of the Polish economy through R&D activities conducted for their exclusive benefit. We refer here to initiatives like INNOLOT (aviation), INNOMED (medicine) or INNOTEXTILE (textile industry) launched by the National Centre for Research and Development.

Another type of incentive designed to boost the Polish R&D market are "loans for technologies" granted to enterprises on a call-off basis. The grantee is obliged to introduce a technology, and in turn part of the loan is paid off through the EU co-funding scheme ("technological bonus"). R&D tax exemptions are also intended to induce the private sector to invest – entrepreneurs are allowed to decrease their tax base by the cost of new technology purchased from a Polish or foreign university or research institute (enterprises with the status of an R&D centre included), not exceeding 50.0% in the case of SMEs and 30.0% for others. The R&D expenses are tax deductible irrespective of the results of the R&D activity [22].

Table 2. Polish programmes co-funded by the European Union 2014–2020 (Source: Authors' analysis)

Financial Perspective 2014–2020		
Operational Programme Smart Growth (PO IR)	8.6	• Stimulating R&D and transferring the results to the economy
Operational Programme Infrastructure and Environment (PO IiŚ)	27.4	• Investments in support of transition to low-emission economy • Energy efficiency increase • Use of renewable energy sources
Operational Programme Knowledge, Education, Growth (PO WER)	4.7	• Development of personnel competences and skills
Operational Programme Eastern Poland (PO PW)	2	• R&D support • Building and expanding R&D facilities • Eco-innovation and energy efficiency leading to innovation
Regional Operational Programmes (RPO)	31.20	• Economic development of Polish regions through smart specialisations
Operational Programme Digital Poland (PO PC)	2.2	• Construction, extension or restructuring of broadband Internet access • Support for e-administration and e-services in collaboration with local and central government administration • e-integration and e-activation to increase intensity and quality of Internet use
Technical Assistance	0.7	• Building the potential of public institutions distributing EU funds
Total	**76.8**	

3. Barriers to Poland becoming a knowledge-driven economy

Ref. [15] specified the barriers facing the Polish R&D market. They were divided into supply, demand and transmission mechanisms. We analysed the available data and mapped them to the barriers presented in [13], adding our own observations. The summary results are shown in Table 3.

The consequences arising from the barriers shown in Table 3 result in a lack of synchrony for joint activities undertaken by universities and businesses. Significant deficits in the process of commercialising research results in Poland might result from the business–academia relationship in terms of common R&D projects presented in Figure 3.

A good model of business–academia partnership is shown in Figure 3A, and this situation is typical for economies with a developed R&D market. The enterprise and university go work hand in hand on a potential technology. For enterprises, the stage called "research stage" by universities is in fact pre-investment. From the point of view of a university, the second stage means prototyping and validating the prototypes to remove the faults unidentified at the research stage, while for enterprises it means investment. At the operational stage the

technology enters the market. The whole process of translating research results into a product might take more than a decade.

Table 3. Barriers for the transition of the Polish economy into the knowledge-driven economy (Source: Authors' analysis)

Item	Barriers
Demand	• no interest of enterprises in innovation; • slow development of innovation culture and little experience in cooperation with universities; • decision centres located abroad in the case of the majority of large enterprises; • slow development of financial markets in terms of financing innovation; • achieving good results of economic activity without the necessity to take the risk of introducing new technologies; • lack of "self-awareness" of Polish enterprises; • lack of knowledge on available home-made innovative technologies.
Supply	• little attraction of the demand, weak transmission mechanisms, lack of effective market regulation policy; • little or no interest of researchers in commercial aspects of R&D; • lack of experience and skills to cooperate with business; • lack of expense and income settlement mechanisms at universities and research institutes; • internal blocking mechanisms at universities and research institutes, e.g. vertical management structures; • tolerance for and availability of "soft" funding, lack of pressure on long term income from commercialisation; • decrease of human capital quality; • long time to reach research results by universities.
Transmission mechanisms	• lack of market need for brokerage services; • lack of effective support of market regulation Policy; • unspecified competences of institutions participating in implementing the knowledge-driven economy; • inability of R&D market actors to define their expectations towards each other.

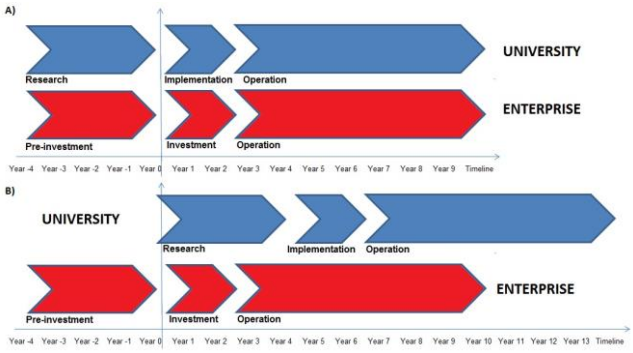


Fig. 3. Process of commercialising research results: A) standard, typical for knowledge-driven economies, B) shifted, identifiable now in Poland. (Source: Authors' analysis based on [19]).

The model presented in Figure 3B reflects the current Polish situation for the main R&D market actors. Because business–academia cooperation is disturbed, universities do not verify the utility of the research results they obtain with their potential receivers. This means that the receiver (enterprise) purchasing the research results must repeat the first stage (pre-investment) and the whole process lingers on. In other words, Polish universities make technologies first and then seek investors to go to market. Investors will not take the financial risk to invest in unproven technology thus, at best, will move back to the previous stage of pre-investment or, as is more common – withdraw.

4. Conclusions

Polish enterprises will receive meaningful financial support from the EU between 2014 and 2020, and the fact that they are obliged to co-invest will certainly ensure greater effectiveness of the spending. It is doubtful, however, if the EU funds earmarked for building R&D facilities by the private sector will be consumed effectively taking into account the structure of the Polish market and the predominance of service sector SMEs.

Poland has started to polarise in terms of R&D: the distance between Mazovian, Lesser Poland, Silesian, Lower Silesian, Greater Poland, Lodz and other Polish regions has increased. The governmental sector still has the largest share in the R&D financing structure, so the R&D market is not determined by free market mechanisms but by political decisions. Polish enterprises are still able to achieve economic benefits and compete through low labour costs without the necessity to invest in innovations. What is more, they are very likely to purchase the technology they need abroad, because it is proven and went through the stages shown in Figure 3 at someone else's risk.

The business–academia relationship for joint projects shown in Figure 3 leads us to the conclusion that in 2016 it is questionable if Poland has the knowledge, R&D personnel and research results to meet the expectations of innovative enterprises. Polish universities and research institutes face the greatest challenge: because they are accustomed to the traditional model of state grants, they are rarely motivated to generate their income from commercialising R&D results which, as a matter of fact, do not meet the expectations of the private sector. On the other hand, EU funds are no substitute for a state innovation policy where the roles and expectations of each R&D actor are precisely defined.

According to [6] the transition from an industrial economy to a knowledge-driven economy is characterised by:

1) Dematerialisation – transforming tangible assets into intangible assets that build the value of the enterprise; knowledge becomes the source of competitive advantage.
2) Dynamics – innovative rivalry, fast product generation and short life-cycles; imitation strategy replaced by the need for innovation.
3) Decentralisation – development of manufacturing networks and flexible business models.
4) Uncertainty (turbulent economy) – nothing is certain; a prosperous enterprise today might not exist tomorrow.
5) Globalisation – increase in market range (global village).

Summarising, there are still many years of hard work and investments ahead if Poland is to make headway toward a knowledge-driven economy. The stage Poland is at now is mainly the consequence of the unfavourable historical events of the 20th century and the enormous destruction that followed. However, dynamic changes occurring in Poland in recent years at governmental, social and economic levels, as well as the support provided by the EU will certainly allow Poland to close

the gap with other developed economies. A goal that Poland is very ambitious about.

Acknowledgements

This publication is financed through a research grant of the Ministry of Science and Higher Education of Poland 4/S/ITESO/14: “Diagnostics methods and efficient operation of complex technical systems in terms of failure prevention and environmental protection”.

References

[1] Central Statistical Office. Działalność badawcza i rozwojowa w Polsce w 2014r. (R&D in Poland), Warszawa, 14.10.2015.

[2] Columbia: First Shuttle in space. Website: http://www.space.com/18008-space-shuttle-columbia.html [accessed: 25 June 2016].

[3] Chybowski L, Idziaszczyk D, Wiśnicki B. A Comparative Components Importance analysis of A Complex Technical System with The Use of Different Importance Measures. In: Systems Supporting Production engineering. Review of Problems and Solutions. Kaźmierczak J, editor. Monografia, P.A. NOVA, Gliwice 2014, s. 23-33.

[4] Chybowski L., Idziaszczyk D., O antropocentrycznym i technocentrycznym podejściu w procesie tworzenia innowacji (Anthropocentric and Technocentric Approach in Creating Innovation). Systemy Wspomagania w Inżynierii Produkcji. Inżynieria Systemów Technicznych z. 2(11) (red. J. Brodny, Ł. Dziemba). Monografia, Gliwice: P.A. NOVA. Pp. 51-63.

[5] EU Funds in Poland 2014–2020. Website: http://www.roedl.com/pl/en/services/state_aid_advice/eu_funds_in_poland_20142020.html [accessed: 25 June 2016].

[6] Gospodarka oparta na wiedzy. Portal innowacji (Knowledge-driven economy. Innovation Portal). Website: http://www.pi.gov.pl/parp/chapter_96055.asp?soid=256993FED9734DD0B31A4785E53F81F5 [accessed: 25 June 2016] .

[7] Hatzichronoglou T., Globalisation and Competitiveness: Relevant Indicators. STI Working Papers 1996/5, Paris: OECD, 1996.

[8] Hernesniemi H, Lammi M, Ylä-Anttila P. Advantage Finland: The Future of Finnish Industries. In: ETLA Series B-113 and SITRA 149. Helsinki: Taloustieto Ltd., 1996.

[9] History of Computers and Computing. Website: http://history-computer.com/ModernComputer/Basis/floppy_disk.html [accessed: 25 June 2016].

[10] Innovation Union Scoreboard 2015. EC report. European Union, 2015, doi: 10.2769/247779.

[11] K-202. Wikipedia. Website: https://pl.wikipedia.org/wiki/K-202 [accessed: 25 June 2016].

[12] Kalendarium historyczne, lata 60-te i 70-te (Historic calendar of Poland in the 1960s and 1970s). Polish Patent Office. Website: http://www.uprp.pl/lata-60-te-i-70-te/Menu10,111,2,index,pl/ [accessed: 25 June 2016]

[13] Kaźmierczak J. Innowacyjność: uwarunkowania i perspektywy w warunkach polskich (Innovation: Polish conditions and perspectives). Uniwersytet Śląski, KZZ 2009.

[14] Melex. Website: http://www.melex.com.pl/o-firmie/historia [accessed: 25 June 2016].

[15] Orłowski WM, Komercjalizacja badan naukowych w Polsce. Bariery i możliwości przełamania (Commercialisation of research results in Poland. Barriers and opportunities), PwC, Warszawa lipiec 2013.

[16] Portal Funduszy Europejskich (Portal of European Structural Funds). Website: https://www.funduszeeuropejskie.gov.pl/ [accessed: 25 June 2016].

[17] Porter ME. The Competitive Advantage of Nations. London: Macmillan, 1990.

[18] Powell WW., Snellman K. The Knowledge Economy. Annu. Rev. Sociol 30, 2004. pp 199-220. doi: 10.1146/annurev.soc.29.010202.100037

[19] Półkoszek A. Wycena technologii - materiały szkoleniowe (Technology valuation – training materials), BOMIS, Poznań 2016.

[20] Raport o stanie patentowania w Polsce. Patenty szansą na wzrost innowacyjności polskich przedsiębiorstw (Report on patenting in Poland. Patents as a chance for the innovation growth of Polish enterprises), 28 maja 2015. Warsaw: CRiDO Taxand, 2015.

[21] Routti J. Research and development for knowledge economy, w: Towards a New Creative and Innovative Europe, Nowy Sącz: WSB-NLU, 2007.

[22] Rozwiązania podatkowe wprowadzone Ustawą o niektórych formach wspierania działalności innowacyjnej (Taxes and tax exemptions introduced by the Act of supporting innovative activity). Website: http://www.pi.gov.pl/finanse/chapter_95014.asp [accessed: 25 June 2016]

[23] Świda A. Kreatywność w gospodarce. Kształtowanie zachowań innowacyjnych, przedsiębiorczych i twórczych w edukacji inżyniera (Creativity in economy. Developing innovative, entrepreneurial and creative behaviours among STEM students). Wrocław: Wyd. Indygo Zahir Media,2011. pp 25-26.

[24] Wpływ sektora B+R na wzrost konkurencyjności polskiej gospodarki poprzez rozwój innowacji (The influence of the R&D sector on the competitiveness of the Polish economy through innovation). Jegorow D, Niedużak A, editors. Vol 2, Chełm, 2012

Roadmapping the Disruptive Innovation Technologies Based on CV of Resource

Jianguang Sun[1*], Yu Wang[1], Lizhen Jia[1,2], Runhua Tan[1]
[1]Hebei University of Technology, China; [2]Politecnico di Milano, Italy

* E-mail: ssunjg@126.com

Abstract

Different from the sustaining innovation, disruptive innovation is a kind of cheap, convenient and simple product innovation. The realization of the technology can make new corporations achieve successful entrance into the market and effective growth. Because the existing disruptive innovation of technology forecasting and implementation method have not carried on the analysis of the system resources, the realization of the effectiveness cannot be guaranteed. This paper carried out in-depth research on the system resources of the disruptive innovation process, especially on the coefficient of variation (CV) of the resources, combined the decomposition and analysis methods of the existing technology system, used the TRIZ tool and established a destructive innovation technology forecasting process model that is based on the resource analysis. Finally, an innovative case of an electric screwdriver was presented to validate the proposed theory.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.
Keywords: Disruptive innovation; Resource analysis; Technology forecasting

1. Introduction

Disruptive innovation refers to the introduction of products that, in terms of mainstream performance, are lower than the products existed in the mainstream market, but have some features that attract the less important users or new users, and gradually gain a firm foothold when developed in the low-end market and new market, then finally replace the finalized product of mainstream market. The enterprise that have these products will replace the original enterprise. This process, in which the original enterprise is defeated by the enterprise with these kinds of product, is the disruptive innovation. Disruptive innovative products are generally characterized by relatively low price, simple structures, small size, easy operation and some other features. It is these features that attract some of the users and make the product form the competition with finalized products of mainstream market.[1,2,3] Disruptive innovation usually destroys the original technology competition network [4],and builds a new market pattern.

Resource analysis is one of the methods of TRIZ analysis. At present, the application of resources is more and more important in the engineering practice. Analyzing system resources can not only improve the ideal level of a system , but also reduce the resource consumption to meet the needs of users with fewer resources. And the minning of potential resources can increase the utilization rate of resources. In the process of product design, it is very important to find and determine resources in a system or super-system for solving engineering problems. Summarizing the research achievements in the field of TRIZ, Zlotin Alla and Zusman Boris divided the resources into two categories: Inventive Resources and Evolutionary Resources[5].

Disruptive innovation is a special branch of technological evolution route. Different from the sustaining innovation, disruptive innovation technology is not focused on the continuous improvement of mainstream functions [6]. The technology forecasting process of disruptive innovation is mainly based on technology evolution route[7]. There are two types: requirement–pull mode and technology-push mode. The former type is originated from market, according to the new market-requirement planning disruptive innovation strategies. While, the latter one is from the technology system of target product status, depending on its existing resources, as shown in Figure 1. This paper mainly explores the

formation process of disruptive innovation strategies that based on resource analysis.

The implementation of any innovation can not be separated from the application of resources. Disruptive innovation is characterized by changing the auxiliary function or reducing the corresponding mainstream function to realize the innovation. In this process, the application of the corresponding resource will also change. The innovation point of this paper is through the application change data of statistical product resources to find the auxiliary function of a product that need to change, and then achieve the effective disruptive innovation.

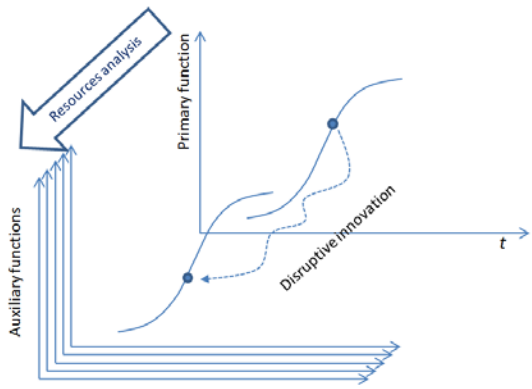


Fig. 1. Disruptive innovation process based on resource analysis

2. The formation of disruptive innovation strategies based on resource analysis.

On the basis of analyzing the existing forecasting method of disruptive innovation, it was known that the timing of disruptive innovation technology appears, accompanied by the imbalance of a product system. Therefore, this paper proposed a new method to forecast the timing of disruptive innovation technology based on resource analysis.

If a product is in the mature stage, target system resources according to the above classification could be divided into six categories with their corresponding product information respectively. Material resources: product weight, material quality. Field resources: energy consumption of products before the completion of the corresponding function. Exceptionally, some products do not consume energy, such as the cup. Space resources: the product work space when completing the main function, different requirements on space sizes for different products. Time resources: the time to complete the main function. Function resources: number of functions completed by the target system. Information resources: the necessary control parameters to achieve the main function of products. For different products, the selection of the corresponding data may be different. Some products may not contain one or more of them. The product resource data was organized as shown in the table 1, in which Su denotes the material, Fi denotes the field, Sp means the space, T means the time, Fu is for the function and In is for the information. The column in the table represents resource type, and the row represents different products[4,6].

The steps to seize the opportunity for the implementation of disruptive innovation technology through the product resource data table are as follows:

- First step, complete the resource data table.

Select the product data of corresponding resource types according to the table, and find the same type from the product data, then fill them in the table.

Table 1. product resource data

Sample	Su	Fi	Sp	T	Fu	In
1	X1	Y1	Z1	A1	B1	C1
2	X2	Y2	Z2	A2	B2	C2
3	X3	Y3	Z3	A3	B3	C3
……	……	……	……	……	……	……
r	Xr	Yr	Zr	Ar	Br	Cr
……	……	……	……	……	……	……
n-1	Xn-1	Yn-1	Zn-1	An-1	Bn-1	Cn-1
n	Xn	Yn	Zn	An	Bn	Cn

- Second step, data standardization.

The six kinds of product resources are from different dimensions of physical quantities and have different units. Therefore, it is necessary to standardize the data. In the current literatures, there existed some methods to do it: maximization treatment, minimization treatment, min-max normalization treatment and Mean method treatment. Therein, mean method treatment can reserve the information of variation degree and mutual influence degree of each index in the original data, which can eliminate the effects of the dimension and quantity of the data, making the result more accurate. Therefore, in this paper, we applied mean method treatment to process the data, and keep the information of the discrete degree between the data.

$$\mu = \frac{1}{\mathrm{N}} \sum_{i=1}^{\mathrm{N}} X_i \tag{1}$$

$$x_i = \frac{X_i}{\mu} \tag{2}$$

In the formula (1) and (2) , X_i denotes the original data, N denotes the number of data, μ is for the average of the data, x_i means the data after the treatment.

- Third step, calculate the extent of resource usage.

Calculate the product resource data, determine the timing of the forecasting according to the results.

In probability and statistics, coefficient of variation, known as "discrete coefficient", also is known as the standard deviation rate or unit risk, denoted as CV. It is a normalized measurement for the discrete degree of probability distribution, and it is the ratio of the standard deviation and the average value, which requires that the average value is not zero.

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{3}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \mu\right)^2} \tag{4}$$

$$C_V = \frac{\sigma}{\mu} \tag{5}$$

The formula (3), (4), (5) signify the process of calculating the CV, where x_i is the data after the treatment. N is the number of the data, μ represents the average value of the data, σ is a group of the data of the standard deviation. If the CV of a certain set of the data is large, it means that the discrete degree of this set of data is large, implying that this kind of resource is often considered in the product design, even over used and so will carry low application potential. On the contrary, if the CV of a certain group of the data is small, it shows that the fluctuation of this group of the data is smooth, indicating that the exploitation of the corresponding resources are insufficient to the current data in the development of this product. So they are often ignored in the product design, implying much higher application potential[8].

- Fourth step, the timing forecasting can be obtained by comparing the CV

After calculating and obtaining the results, the CV will be sorted by an ascending order, denoted as CV1 to CV6. Among them, CV1 and CV2 are minimal, indicating that their corresponding resource usage is insufficient, and the utilization of these two kinds of resources should be improved in the prediction of the disruptive technology; CV3 and CV4 are the intermediate value, meaning that the corresponding resource fluctuation is more average, and they cannot be used as the opportunity of disruptive innovation. The value of CV5 and CV6 are the largest, which means their corresponding resources fluctuate largely and are used excessively in the product, so in the disruptive technology forecasting, the use of these two kinds of resources should be reduced.

3. Case study

We will take the electric screwdriver as an example to illustrate the above operation steps in this part. Through the resource properties analysis of the product data of the hand-held electric screwdriver, it could be known that material resources corresponded to the weight, field resources corresponded to the power, time resources corresponded to speed, space resources corresponded to the volume, information resources corresponded to the torque, functional resources corresponded to the type of knife head. Table 2 shows the final resource data of a series of electric screwdrivers.

Taken the column of weight as an example, the average value of the weight was 527.5 (g) according to the formula (1), and then according to the formula 2, the standard average data was computed. For instance, the weight of the WCS250A electric screwdriver is 650 (g), and is turned into 1.23 after the standardization. All the standardized data is shown in the following table 3.

Table 2. resource data of electric screwdriver

Model	Weight (g)	Power (w)	Speed (rpm)	Volume (mm^3)	Torque (N*m)	Type of knife head
WCS30A	450	30	1000	7722	0.165	1
WCS30D	450	30	1000	7722	0.165	1
WCS100A	450	30	1000	7722	0.6	4
WCS100D	450	30	1000	7722	0.6	4
WCS160A	560	30	1000	9576	1	3
WCS160D	560	30	1000	9576	1	3
WCS250A	650	30	1000	10450	1.6	3
WCS250D	650	30	1000	10450	1.6	3

Table 3. standard data table for electric screwdriver

Model	Weight	Power	Speed	Volume	Torque	Type of knife head
WCS30A	0.85	1	1	0.87	0.2	0.36
WCS30D	0.85	1	1	0.87	0.2	0.36
WCS100A	0.85	1	1	0.87	0.71	1.45
WCS100D	0.85	1	1	0.87	0.71	1.45
WCS160A	1.06	1	1	1.08	1.19	1.09
WCS160D	1.06	1	1	1.08	1.19	1.09
WCS250A	1.23	1	1	1.18	1.9	1.09
WCS250D	1.23	1	1	1.18	1.9	1.09

Based on the formula of the CV, we could get the following results: the CV of the weight is 0.1588, the CV of the power is 0, the CV of the rotational speed is 0, the CV of the volume is 0.1338, the CV of the torque is 0.6308, the CV of the knife head type is 0.3963. Among them, the CV of the torque is biggest and the type of knife head is the second, while the CV of the power and rotational speed are both smaller than others. Therefore, product innovation in the past

is committed to the increasement of torque and the type of knife head, which is regarded as the "parametric innovation". Since the CV of the rotational speed is 0, changing the application of this resource would make disruptive innovation opportunities appear. As it belongs to time resource, there are two possible ways to innovate, according to the trends of being larger or smaller for time resource:

(1) Increasing the speed: Developing a high power product that is based on the specialization of requirement evolution. We can use the dual power supply mode of external power supply and internal battery to solve the insufficient torque problem under the condition of high speed.

(2) Decreasing the speed: Developing an ultra low speed product to realize the sufficient speed under low power, it can be integrated a hand-held power generation device which can be used for emergency to ensure the output torque.

4. Conclusions

Multiple disruptive innovation opportunities could be discovered via the technology-driven pattern, wherein resource analysis played an important role. The CV analysis of resources can provide a theoretical foundation for the application of disruptive innovation technology, and it may also improve the success rate for entering the mainstream market in the future.

Acknowledgements

This paper is supported by the National Natural Science Foundation (Grand No: 51275153) and the State Scholarship Fund from China Scholarship Council.

References

[1] Christensen, Clayton M. The Innovator's Dilemma. When New Technologies Cause Great Firms to Fail. Boston, MA: Harvard Business School Press, 1997.

[2] Christensen, Clayton M. and Bower, Joseph L. Customer Power, Strategic Investment, and the Failure of Leading Firms. Strategic Management Journal, 1996 17(3):197-218.

[3] Christensen, Clayton M. and Overdorf, Michael. Meeting the Challenge of Disruptive Change. Harvard Business Review, 2000 78(1):67-76 (March).

[4] Abernathy W. J., Clark K.B. Innovation: Mapping the winds of creative destruction [J]. Research Policy, 1985, 14(1):3-22.

[5] Boris Zlotin, Alla Zusman. The Concept of Resources in TRIZ: Past, Present and Future. http://www.ideationtriz.com/new/materials/finalconceptresources.pdf, 2004.

[6] Jian G. Sun, Runhua. Tan, Jing Guo, Tianlin Chai, Xiaolong Liu Analysis on Technological Opportunities of Evolution Bifurcations. Procedia Engineering, Volume 131, 2015, Pages 1113-1120.

[7] Sun. J. G, Tan, R. H. Method for forecasting DI based on TRIZ technology system evolution theory. International Journal of Innovation and Technology Management, 2012, 9(2): 1250010(1–20).

[8] Koichi Makion, Manabu Sawaguchi. Investigation about the feasibility and impediments of TRIZ application in architectural design process [C].TRIZ FUTURE CONFERENCE 2013,233-243.

Statistical use of the TRIZ contradiction matrix, experimentation on a ball bearing technical issue

Elie Aupetitgendre[ab], Laurent Varnoux[a], Nicolas Maranzana[a]*

[a]*SKF France, 204 Bd Charles de Gaulle, St-Cyr-sur-Loire 37520, France*
[b]*Arts et Métiers Paritech, 151 Bd de l'Hôpital, Paris 75013, France*

* Corresponding author. Tel.: +33-014-424-6233. *E-mail address:* nicolas.maranzana@ensam.eu

Abstract

Altshuller's Theory of inventive problem-solving (TRIZ) is recognized to have high potential for technical innovation generation, especially the contradiction matrix tool. But its application can be tricky. It is time-consuming, requires experience with specific methodologies and results are far from guaranteed. These statements have led to a discussion on a simplified use of the contradiction matrix. Given that the matrix stems from the results of statistical analysis of the most common inventive principles used to solve given problems, one can consider a wider, more exhaustive application of its uses. The idea consists in identifying every important feature of a given system, and then measuring the occurrence frequency of inventive principles. This allows for a quicker understanding of which principles are most commonly used for a given set of features. This method and its potential benefits have been experimented on with a practical study case: a ball bearing technical issue as part of the activities of a Development Office within the *SKF* organization. This article proceeds in three main sections. A statement of the difficulties inherent to the use of the contradiction matrix will be done in the first part. Then propositions for new uses of this matrix will be established. Finally, case study results will be detailed to assess the potential of the investigated method.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: technical problem solving; TRIZ; contradiction matrix; simplification; statistics

1. Introduction

1.1. Seemingly-simple theory

The starting point of Altshuller's work was the understanding of the act of innovation, which has led to the identification of generic invention patterns reoccurring across industries. Thus, he has defined technical systems evolution laws by analyzing more than 400,000 patents containing actual innovative solutions.

Nowadays, TRIZ is recognized as a powerful "systematic innovation" theory and used by leading companies such as *Samsung*, *Ford*, *IBM* and many others. Several methods and tools have stemmed from this original theory. [1] [2] The most practical and exhaustive of these tools is probably the Contradiction Matrix. [3] Indeed, one of the main ideas of this theory is that every technical problem can be addressed by overcoming "contradictions" between a limited number of parameters. These technical contradictions reoccur across industries, which has led to the identification of generic *inventive principles* used to solve them.

This *contradiction matrix* can be described as the logical outcome of the invention pattern analysis process. It is presented in the form of a double-entry table, containing a matrix of 39 technical features. To solve a problem, a "feature to improve" has to be selected (Fig. 1; line entry) along with a related "worsening feature" that has to be preserved (Fig. 1; column entry). For instance, if the aim is to develop a pen that can contain more ink, the *quantity of substance* could be selected as a feature to improve, and the *weight of stationary object* as a feature to preserve, because the object must be kept lightweight.

Extract of the *contradiction matrix* table

FEATURE TO IMPROVE \ WORSENING FEATURE	1. Weight of moving object	2. Weight of stationary object	3. Length of moving object	4. Length of stationary object	5. Area of moving object	6. Area of stationary object	7. Volume of moving object	8. Volume of stationary object
1. Weight of moving object			15, 8, 29, 34		29, 17, 38, 34		29, 2, 40, 28	
2. Weight of stationary object				10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2
3. Length of moving object	8, 15, 29, 34				15, 17, 4		7, 17, 4, 35	
4. Length of stationary object		35, 28, 40, 29				17, 7, 10, 40		35, 8, 2, 14
5 .Area of moving object	2, 17, 29, 4		14, 15, 18, 4				7, 14, 17, 4	
6. Area of stationary object		30, 2, 14, 18		26, 7, 9, 39				
7. Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17			
8. Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				

INVENTIVE PRINCIPLES

7. Nesting

17. Moving to a new dimension

4. Asymmetry

35. Transformation of the physical and chemical states of an object, parameter change, changing properties

Fig. 1. Usual use of the TRIZ contradiction matrix.

Once the two features are identified, the matrix refers to the inventive principles that are the most commonly used to solve this contradiction (e.g. *cheap disposable objects*, like replaceable ink cartridges for the pen example). [3] As *TRIZ* seeks ideality, these inventive principles are the one having the slightest impact on the system. [4]

This way is classicaly used the *contradiction matrix*. [5] It can be easily understood that this tool has great potential to orient product developers to tracks of innovative solutions. But in practice, many difficulties can be faced.

1.2. …But difficult practice

First of all, the matrix can appear as a ready-to-use tool that particularly fits continuous product improvement and incremental innovation. However, it does not allow to avoid deep analysis and preparation that must be carried out prior to any problem-solving activity. The problem needs to be well-known and well-defined by the people in charge of its solving. This requirement is not specific to the use of the contradiction matrix, but considering that the problem is solved through the resolution of a very specific technical contradiction, it becomes increasingly important. [4] Coming back to the pen example, it is clear that if the actual issue was to reduce ink consumption, the features selected in the matrix, and thus the potential solutions would have been very different.

In order to identify the appropriate technical contradictions of a given problem, it is often necessary to perform in-depth analyses, such as problem timeline study, sequential modelling or to focus on the system's main characteristics. [6] [7] This requires TRIZ theory training and experience.

Moreover, even if the person in charge of problem solving is very familiar with it, several features can be relevant most of the time, depending on the system complexity. Making sure that the selected features are the most relevant can prove difficult. In order to determine whether a feature has to be selected as one "to improve" or "to preserve" can also be very ambiguous. These choices can lead to lengthy discussion and prevent from any actual decision-making.

Testing all the potential feature combinations is possible, however, investigating the entirety of possible inventive principles could prove tedious and time-consuming, with none clearly standing out as a lead.

2. Hypotheses

2.1. Contradiction matrix used as a statistical tool

The *TRIZ* theory can be seen as the result of statistical analyses, which have permitted to identify generic *inventive principles* used to overcome reoccurring *technical contradictions*. [3] In a way, the main idea behind this theory is that when a technical problem arises, someone else already had to solve a similar issue. The contradiction matrix only indicates how this type of problems are usually solved. Thus, *TRIZ* can be seen as a pioneer in "open innovation". [3] [8]

Based on this statement as well as the assessment that problems can be treated in various ways, as explained previously, one can make the following assumption:

By selecting all relevant technical features for a given problem, the matrix would yield the inventive principles most commonly used to solve inherent contradictions.

In other words, the *contradiction matrix* can be used more exhaustively, in a way that does not require any trade-offs in the identification of the contradiction.

Such a method would allow most exhaustive overview of relevant inventive principles for a given problem, with a clear benefit: the risk of focusing on the wrong features would be eliminated. Indeed, all technical features that matter in the system are thus taken into account.

To assess the validity of this assumption, a tool enabling to perform multi-criteria analysis was implemented based on the *contradiction matrix*. This tool enables to select all the features that matter to a given problem. Eventually, the user can allocate importance levels to the selected features, major

or minor (Fig. 2; Dark blue for major and light blue for minor), in order to give more weight to the most important ones. Once the selection of the *features* is done, a set of contradictions is obtained. (Fig. 2; blue cells) The database counts the inventive principles that correspond to each of these contradictions. It returns the results as a *Pareto* diagram which brings out the most frequent principles.

Extract of the *contradiction matrix* table

FEATURE TO IMPROVE \ WORSENING FEATURE	6. Area of stationary object	7. Volume of moving object	8. Volume of stationary object	9. Speed	10. Force (Intensity)	11. Stress or pressure	12. Shape	13. Stability of the object's composition
16. Duration of action by stationary object			35, 34, 38					39, 3, 35, 23
17. Temperature	35, 38	34, 39, 40, 18	35, 6, 4	2, 28, 36, 30	35, 10, 3, 21	35, 39, 19, 2	14, 22, 19, 32	1, 35, 32
18. Illumination intensity		2, 13, 10		10, 13, 19	26, 19, 6		32, 30	32, 3, 27
19. Use of energy by moving object		35, 13, 18		8, 35, 35	16, 26, 21, 2	23, 14, 25	12, 2, 29	19, 13, 17, 24
20. Use of energy by stationary object					36, 37			27, 4, 29, 18
21. Power	17, 32, 13, 38	35, 6, 38	30, 6, 25	15, 35, 2	26, 2, 36, 35	22, 10, 35	29, 14, 2, 40	35, 32, 15, 31
22. Loss of energy	17, 7, 30, 18	7, 18, 23	7	16, 35, 38	36, 38		14, 2, 39, 6	
23. Loss of substance	10, 18, 39, 31	1, 29, 30, 36	3, 39, 18, 31	10, 13, 28, 38	14, 15, 18, 40	3, 36, 37, 10	29, 35, 3, 5	2, 14, 30, 40

Parameters importance levels

Major | Minor

Pareto diagram of the most common *inventive principles* used for the selected features

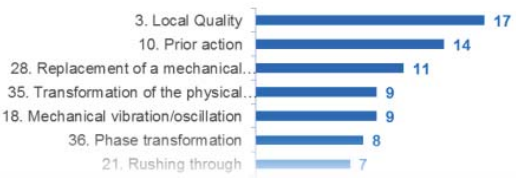


Fig. 2. Statistical use of the TRIZ contradiction matrix.

The "major" and "minor" importance levels were integrated as an option. If the user wants to take this into account, a factor two is allocated to the inventive principles to give them more weight when one of their technical features was selected as "major" and a factor four when both are "major". It appears that this importance distinguishing has only a very slight influence on the final ranking. With or without it, the most frequent inventive principles remain the same. This option can be used or not according to the accuracy level wanted for the results.

In a more general way, this manner of using the *TRIZ contradiction matrix* permits to encompass the entire complexity of the studied problems, which are often multifactorial. [2] Moreover, even if the person in charge of the problem manages to identify the right contradiction, the matrix will only return to tracks of solutions and the inventive work will remain to do. Indeed, the inventive principles are not ready-to-use solutions and requires further analysis to see if they can be applied to a specific problem. The multi-criterion analysis can give more inventive principles to investigate thus more potential solutions, in addition to the fact that the risk of focusing on the wrong contradiction can be avoided.

2.2. Simplified use of the contradiction matrix

To push further the analysis, one assumes that the important parameters to the studied system could be considered without questioning whether it is a "feature to improve" or a "feature to preserve". This new assumption can be formulated as following:

Selecting all the relevant features to a given problem and considering all the contradictions between these features could permit to bring out relevant inventive principles.

Indeed, considering that the *contradiction matrix* returns the statistically most common generic solutions to given problems, one could assume that it could lead to the most commonly used inventive principles for a set of features as well.

This means that the problem solver would only select the technical features that matter to his problem. The outcome would be the inventive principles occurrence frequency for the contradictions between these selected features. In the implemented tool, the features are selected in one entry of the table only and the same selection is automatically filled in the other one (Fig. 4). Such a method, if validated, would make the use of the *contradiction matrix* simpler again. Indeed, for the users, this only supposes knowledge of the constraints of the technical problem. There would not be necessary to wonder if the features are "to improve" or "to preserve", which is often very ambiguous.

Compared to the previous considered method (Fig. 3), more contradictions are accounted. To evaluate the potential of this second method, it is necessary to ensure that the thus obtained inventive principles are relevant. For this, the results of these two methods will be compared.

***Contradiction matrix* table overview: multi-criterion analysis with distinction between "*feature to improve*" and "*features to preserve*"**

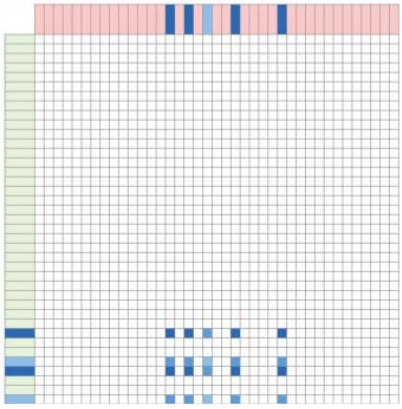


Fig. 3. Classic use with selection of multiple features

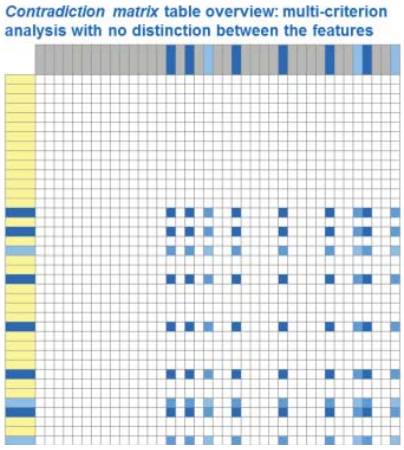


Fig. 4. Selection of all the important features of the system

3. Case study

3.1. Ball bearing sealing solution example

This work was conducted as part of the activities of a Development Office within the *SKF* Group. The tool was implemented for the needs of a development study that cannot be disclosed yet. But to assess the potential of the method, it was tried on a previous product development project for which an innovative solution was already found quite randomly. This one can be discussed freely because its patents are now published.

The innovation in question consists in a reinforced sealing solution for deep groove ball bearings. It is based on a previous version of bearing using a double capping. This solution was very efficient, but had the drawback to use non-standard components, particularly a special elastomeric seal provided with an additional lip sliding on a metallic shield.

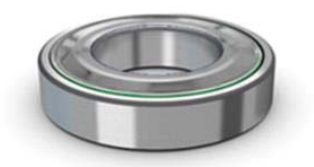


Fig. 5. Ball bearing with flexible metallic seal

To solve this issue, a concept of "metallic lip" was developed (Fig. 5). The sealing contact was inverted to switch from a rubber lip sliding on a metallic counterface to a flexible steel part acting as a seal lip on the elastomer surface of the standard seal. This find was the result of complete serendipity.

The objective is now to apply the studied methods as if the aim was to resolve this problematic, and to compare what is suggested by the contradiction matrix to the innovation which was found.

3.2. Results obtained with the first method (statistical use of the contradiction matrix)

As a reminder, with this first method, some features have been selected as "features to improve" and others as "worsening features", based on the available knowledge on the technical problem to solve. The focus is made on the first height inventive principles brought out by the tool. (Fig. 6).

The first inventive principle that comes out is the number 35: *Transformation of the physical and chemical states of an object, parameter change, changing properties*. This corresponds exactly to what was done without using *TRIZ*. Indeed, the chosen solution consists in a material change for the sealing lip, and a change of property if considering only the metallic shield that has been made thinner and more flexible. The second principle called *inversion, the other way around*, or *upside down* is also very close to what was actually done. Indeed, the functions of the two parts were inverted to obtain the wanted effect.

For the other principles suggested by the matrix, the links with the designed solution seem to be less obvious. But they probably correspond to other potential solutions.

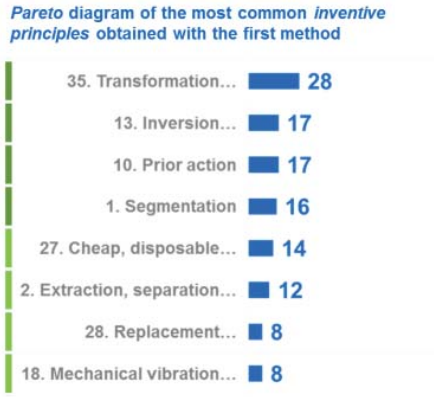


Fig. 6. Inventive principles top 8 obtained with first method

This first experimentation tends to confirm that this way of using the *contradiction matrix* can direct toward relevant potential solutions. The one that stands out the most (with a score of 28 when the second one has 17) could have put the project team on the tracks of the innovative solution reached after long efforts.

3.3. Results obtained with the second method (selection of the important features of the system)

The same method was then applied without considering whether the selected features are "to improve" or "to preserve".

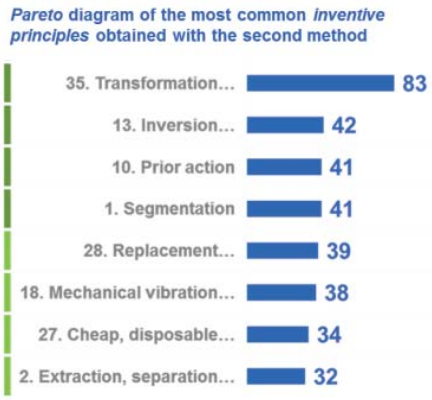


Fig. 7. Inventive principles top 8 obtained with second method

The first thing we can notice is that the results are very similar to the one obtained previously. The first four inventive principles are the same and in the same order (dark green edging on Fig. 6 and Fig.7). In both cases, the first one has almost twice the score of the three ones following, which are very close. This also tends to indicate that such a method would give pertinent results. Of course, deeper investigations with more concrete examples are still necessary to confirm these trends.

4. Conclusion

The first trials done with the multi-criteria and simplified use of the contradiction matrix are promising, pending further investigation.

If the positive results obtained with the method are confirmed, numerous would be the benefits. First, from the technical point of view, this way of doing permits to treat the studied systemas a set of features, and not to limit to only one contradiction between two parameters. Thus, the risk of wrong identification is eliminated.

Then, from a methodological perspective, the users could save time by skipping the long and delicate phase of contradiction identification. The contradiction matrix could be integrated into every development process as a more punctual ideation tool. [9] Finally, inexperienced users could easily make the tool their own and take advantage from the possibilities offered by the *contradiction matrix*.

The method is only at its early stages and its potential remains to be assessed. For this, it is recommended to perform other case studies, eventually with problems taken from other fields.

Acknowledgements

This research draft was done as part of the *SKF* product development activities, under the supervision of Frank Berens, thanks to him.

References

[1] Chechurin l, Borgianni Y. Understanding TRIZ through the review of top cited publications. Computers in Industry, Volume 82, Pages 119-134, 2016.

[2] Chang YS, Chien YH, Yu KC, Chu YH, Chen MY. Effect of TRIZ on the creativity of engineering students. Thinking Skills and Creativity 19. 2015.

[3] Altshuller G. 40 Principles: Extended Edition. 2005.

[4] Wits WW, Vaneker THJ. TRIZ based interface conflict resolving strategies for modular product architectures. TRIZ Future Conference 2010.

[5] Wang FK, Yeh CT, Chu TP. Using the design for Six Sigma approach with TRIZ for new product development. Computers & Industrial Engineering 98. 2016.

[6] Cooke J. TRIZ-based Modelling and Value Analysis of products as processes. TRIZ Future Conference 2015.

[7] Chinkatham T, Cavallucci D. Early feasibility evaluation of Solution Concepts in an Inventive Design Method Framework: Approach and support tool. Procedia Engineering, Volume 131, Pages 1073-1083, 2014.

[8] Polkhrela C, Cruza C, Ramireza Y, Kraslawskia A. Adaptation of TRIZ contradiction matrix for solving problems in process engineering. Chemical Engineering Research and Design, Volume 103, November 2015, Pages 3–10. 2015.

[9] Spreafico C., Russo D. TRIZ industrial case studies: a critical survey. Procedia CIRP, Volume 39, Structured Innovation with TRIZ in Science and Industry: Creating Value for Customers and Society, 2016, Pages 51-56, 2016.

Structured activation of vertex entropy (SAVE): another way around creative problem solving for non-technical applications

Stelian Brad
Technical University of Cluj-Napoca, Romania
E-mail: stelian.brad@staff.utcluj.ro

Abstract

Beyond the indisputable value-added of TRIZ to creative problem solving (CPS), its application in non-technical cases generates difficulties for non-technical people. This paper proposes a tool for CPS related to non-technical applications, called Structured Activation of Vertex Entropy (SAVE). SAVE uses ten vectors for activating non-linear thinking, organized in a specific way to gradually provoke the mind for CPS. In order to test its potential in practice, an empirical experiment was conducted. Three non-technical conflicting problems were given to three focus groups: one led by a TRIZ expert, one trained to use TRIZ contradiction matrix (CM) and supported by a software tool for TRIZ CM application on non-technical problems, and one that uses SAVE. Considering the first group as reference, results from the experiment have been compared and feedback on the experiences from the three focus groups have been collected. The empirical research revealed a good potential of SAVE for CPS and a proper acceptance by non-technical people.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of TRIZ Future Conference 2016.

Keywords: creative problem solving, ideation algorithm, structured innovation, thinking entropy, creative thinking

1. Introduction

TRIZ is a very powerful framework to activate creative thinking. According to many opinions, TRIZ is the most effective approach for structured creativity and systematic inventive problem solving [1]. However, its proper application requires adequate training and a kind of intelligence that works well with abstract things [2]. According to recent surveys, the conclusion is that while TRIZ popularity looks to be on a continuous increase, there are practical issues which make the use of TRIZ in business projects particularly challenging [3]. The challenges recorded by surveys done on people who have tried to use TRIZ count a number of aspects, ranging from the complex nature of the methodology to organizational and cultural issues, which hinder its understanding and application [3].

To explain the issues around effectiveness of TRIZ application in an easier way, a comparison with martial arts is further given. Imagine the case of karate, where a beginner sportsman is asked to perform a fight (kumite) using only four of the techniques illustrated in Figure 1. It is somehow easy to see the fact that the person will prefer the last two techniques instead of the first two because of their convenience with respect to his/her capacities as beginner in this sport.

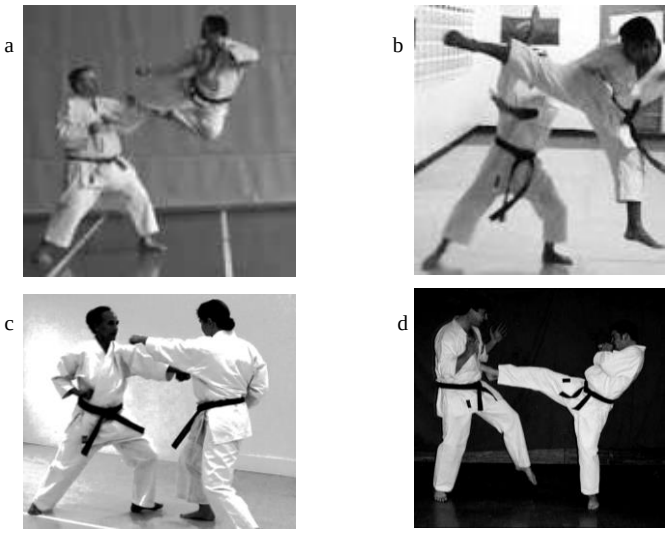


Fig. 1. (a) Yoko Tobi Geri; (b) Ushiro Tobi Geri; (c) Oi Tsuki; (d) Mae Geri.

Considering these difficulties, some researches reported new techniques for inventive problem solving, inspired from TRIZ contradiction matrix (TRIZ CM) but simplified to take into account the less experienced users. Examples of such techniques are: Unified Structured Inventive Thinking (USIT) [4], Advanced Systematic Inventive Thinking (ASIT) [5]. However, an investigation in international databases does not reveal any empirical analysis on their practical effectiveness in comparison with TRIZ.

Literature reports many researches and contributions on creative thinking and tools for creative thinking. Just for indicative purposes, some references are highlighted in this paper [6,7,8]. The issue with all these techniques is they simply act on the vector of psychological inertia of a person and determines to focus his/her mind on a given problem from an unusual or/and completely different angle. This does not automatically mean that the respective perspective is the most appropriate one to tackle the investigated problem. TRIZ claims, based on empirical investigation of millions of patents, that its contradiction matrix (CM) is capable to provide the most appropriate list of vectors where to search for solutions to a particular problem [9].

However, difficulties occur in the model, which requires to abstract a particular problem and then to particularize a generic field of investigation [4]. This is the reason why several researches have been conducted to “translate” and exemplify TRIZ CM inventive principles for various application fields (e.g. management, software, green design, etc.), as well as to develop extensive knowledge bases with examples – mostly from engineering areas.

In the complex landscape of creative thinking tools, a question still arises: Which is the most effective technique to be used for a given particular problem? Still, no research was able to give an answer to this question.

What about the cases of non-technical problems? For example, TRIZ CM has been exercised by many people to solve non-technical conflicts, including the author of this paper. Even if TRIZ contradiction matrix was designed for tackling engineering problems, there are reported cases when it was applied for non-technical problems. A rigorous approach requires generation of the equivalent model of the non-technical problem into an engineering problem … and just afterwards it makes sense to apply TRIZ contradiction matrix. This mode of working with TRIZ for non-technical problems has not been reported in literature. In this context, the intention of training non-technical people to solve in a structured and inventive way provoking problems from fields that do not relate with engineering is still subject to improvements and more explorations. In front of this challenge, it is the purpose of this paper to introduce a technique for creative problem solving in the case of non-technical applications.

The subsequent part of this paper introduces the philosophy that stands behind the proposed technique, followed by a description of the technique. The next section exemplifies the application of the technique in an experiment where TRIZ CM is taken as reference. Results are further commented. Paper ends with a section of conclusions and insights on future related researches.

2. Background

In information theory, systems consist of transmitters, flows of information and receivers. Transmitters send messages through flows, which modify the message in some ways. Receivers infer with messages via information flows. The result is a transformed information. The level of unpredictability of information content is called entropy [10].

For solving conflicting problems, messages are sent to the system. In the system, a message is distorted because of the interactions that occur between different constitutive elements of the system. The higher the internal dynamics in the system, the higher the level of unpredictability of information reflected back by the system. From this perspective, it is somehow desirable to explore different perspectives of the same system such as to understand better its complexity and eventually to formulate a viable solution. This philosophy stands to the basis of the technique proposed in this paper for investigating conflicting problems in the attempt to identify related inventive solutions – solutions that are capable to solve the problem without compromises.

Two issues are seen of high importance in this context. The first one is about the rule for investigating the system. The second one is how to approach investigation such as people trust in the relevance of the effort they have to do. These issues are treated in the next section of the paper.

3. SAVE technique for creative problem solving

In order to investigate conflicting problems in a less abstract way, this paper introduces a technique called Structured Activation of Vertex Entropy, abbreviated as SAVE technique. Its purpose is to activate the system with respect to well defined external stimuli and see the feedback from the system. At every stimulus the system will react in a way and will obtain a certain “shape” (result). The idea is to start with a stimulus and continue with a series of stimuli in accordance with the analysis of the current state of the system such as to direct its evolution to the desired result. In this respect, before starting the application of any stimulus, the final result should be formulated. At every iteration, the gap is determined and another stimulus is applied. In theory, any stimulus and order of stimuli application can be experimented. In practice, a relative small amount of stimuli should be considered, as in the case of design of experiments.

Empirical researches during several years, on different projects run with students, led to the selection of ten SAVE vertexes (or stimuli). They have been primarily extracted from real life examples, considering that such situations convince audience and represent very good models to be followed by usual people. These vertexes are further introduced.

Vertex 1: Activation of resonance – people are asked to modify the system such as it will be capable to resonate (to work at the same frequency) with the painful problem. An example from the real life is the happiness a pet provokes to its master.

Vertex 2: Introduction of neutral elements – people are asked to modify the system such as it will be capable to annihilate the problem by activating a new desirable path of

evolution. An example from real life is the quotation of fiscal receipts from restaurants and hotels at national lotteries organized by the state.

Vertex 3: Action against the wolf-pack spirit – people are asked to modify the system such as it has to operate and reach a target with no support from other systems or with a fully volunteer support from other systems. In real life, there are many examples of persons acting alone to survive from critical situations. In such cases, smarter strategies of deception have to be considered to reach the target. Crowdfunding initiatives to support innovative projects are good examples in applying this principle in the sense of fully volunteer support with no expected reward.

Vertex 4: Activation of centrifugal forces – people have to modify the system such as to benefit from the dynamics of individual elements. Participatory budgeting of public funds is a good example of the application of this vertex.

Vertex 5: Application of multi-level connections – system is modified such as to act in alignment and synergy with other systems. Strategic alliances are examples that respect this principle. Cluster initiatives that promote polycentric innovation are also good examples in this sense.

Vertex 6: Application of asymmetry – system has to be modified such as to counterbalance a much bigger system. Asymmetric wars are very common examples in real life.

Vertex 7: Harmonization of individual goals with collective goals – system is modified such as it is aligned to a higher level target. Bonus allocation based on the performance of the whole team properly reflects this principle.

Vertex 8: Transformation for value-added – people are asked to modify the system such as it can provide more outputs than before, using the same inputs. Lean production is a very good practical example of this stream of action.

Vertex 9: Application of prisoner paradox – people have to use only the existing local resources to solve a given problem by intelligent rearrangement and utilization of those resources. Examples of escapes from prisons are very popular.

Vertex 10: Application of shipwrecked paradox – system has to be modified such as to transform some local negative factors into positive factors by identifying hidden value networks. There are many examples in real life when people survived for long time on isolated islands, in desert or tropical forests, as well as in many other extreme situations.

The ten stimuli are applied on the system in the order indicated by their indexes. The logic is relatively simple, but effective. When you want to solve a problem the first step is to put in the shoes of the others. This reposition might reveal hidden resources that are capable to solve the problem. If still there is no sufficient energy to fix the problem, reveal a new opportunity that will put in balance the current behaviour with something more attractive. If this is not enough, intensify the situation using examples of superior consciousness in the attempt to annihilate the current behaviour of the system. If the situation requires further action, move the system in a given direction as a whole by revealing a potential common danger. At this point of system's transformation, activate new perspectives and let the system to consolidate in places where various gaps are identified by compensating with resources generated from collaboration. From this level of transformation, system might further evolve only with more infusion of non-conventional resources, which are currently hidden due to the status quo of doing things. The leverage effect is activated at this level. More positive effects can be further achieved only by reconfiguration of the existent resources and/or turning harmful things into beneficial ones.

4. Case study and results from the empirical research

To explore the potential of SAVE technique the following experiment was conducted:

- Selection of three groups of executives with similar professional background and professional experience, each group consisting of five persons
- Application of a two-days intensive training on TRIZ contradiction matrix for one of the groups and use of a software tool that supports the application of TRIZ for non-technical problems (the link to this software tool is available at: http://193.226.17.76:8080/sts291-mvc/tool_cmx.do?aProject=1&aSet=1&aAct=1&aTarget=1&aActivityName=1)
- Involvement of a TRIZ expert to lead the second group during the process of problem definition and problem solving
- Application of two hours training program to explain the SAVE technique to the last group
- Running the exercise by asking the three groups to solve three non-technical conflicting problems
- Analysis of results from the three groups in a collective meeting and extraction of lessons to take away

The three problems considered in the experiment are:

- Exercise 1: A software company of 50 people has 5 experts in a niche technology but it needs to train 10 more people in that technology. It faces with the problem this type of training is very expensive.
- Exercise 2: A TV cabling-service company with 250 employees faces with the problem that information dissemination between departments is done with long delays, even if people can communicate via e-mail and other ICT means.
- Exercise 3: A small engineering office with 30 employees faces with the problem that experienced staff is not open to support with advices the less experienced staff, this leading to lower productivity and poor quality issues.

The group being trained two days in TRIZ and supported by a TRIZ software tool faced with difficulties in setting up the appropriate parameters which are in conflict. Thus, for exercise 1, they saw the conflict in the incapacity of the company to pay the training. Thus, the group associated to "improved skills of 10 employees in technology X" the TRIZ parameter "26. Quantity of substance", because the software indicates examples such as money, know-how, output. For

"expensive training" they associated the parameter "19. Effort to involve dynamic elements", where the software suggests for dynamic elements issues such as people, processes, mobile assets, technologies, etc. For this pair of conflicting parameters, TRIZ recommends the following inventive principles: "15. Dynamicity", "3. Increase the local quality" and "29. Reconfigurable construction". Beyond the fact that not these are the proper TRIZ inventive principles for this problem, it was even harder for this group to particularize the generic inventive principles with respect to the analysed problem. The solution proposed by this group for exercise 1 is less relevant – and therefore not introduced in the paper, but in principle it had nothing to do with innovative solutions. Nevertheless, once the problem was inappropriate formulated, the list of inventive principles are less relevant. In other words, there is no difference between TRIZ application for this case and the use of any other tools of creative thinking (e.g. inspirational cards).

For exercise 2, the first group described the conflict as: promptitude in disseminating information versus employees' laziness. The group transposed this problem into TRIZ space as: "19. Speed to execute the task" versus "17. Short-term intensity of the problem (event)/firefighting". The conflict's perspective was wrong again, the group still facing with the same problem of inertia in thinking (Cartesian way of seeing the problem). For this pair of TRIZ parameters, the corresponding inventive principles are: "28. Replacement of a traditional system", "30. Elastic construction", "36. Phase transformation" and "2. Extract, retrieve or remove some parts of the system". Again, the proposed solutions were not very creative.

For exercise 3, the first group modelled the conflict under the form: "improve the commitment of the experienced staff" versus "need for more work". The Cartesian way of thinking was repeated again. This reflects an important aspect for TRIZ application by non-experts. The challenge is not necessarily the capacity of abstraction and particularization, but rather the need for radical change in the thinking patterns of people. After years and years of linear way of modelling and seeing the surrounding systems, it is a big issue how to make people think and see things in a non-linear way. Innovations mostly emerge from out-of-the-box perspectives on things and facts.

Just for the sake of illustrating also this last exercise, the first group generated the following TRIZ pair of parameters: "26. Quantity of substance" versus "25. Waste of time". For this pair, TRIZ proposes the following inventive principles: "35. Transformation of system properties", "38. Use strong motivators", "18. Exploit sensibility" and "16. Partial or excessive actions". Again, it was also a pool of weak solutions to this problem. For example, the inventive principle 38 was mainly exploited under the form of higher salaries to more experienced people for supporting the less experienced people. This solution is not innovative at all; by contrary, it is harmful for the constructive spirit of organization. An important conclusion from the experiment applied on the first group is that TRIZ application by dilettantes is not so effective. This conclusion is aligned with other researches in the field [3].

By contrast, the group led by the TRIZ expert had a better identification of conflicts. It is important to highlight the fact that the TRIZ expert limited his interventions strictly to guide the group, not to identify and provide the correct problems. Thus, for the first exercise, using the guidance of the TRIZ expert, the second group put the problem like this: "39. Capacity (productivity)" versus "26. Quantity of substance". The related inventive principles are: "35. Transformation of system properties (flexibility, density, etc.)" and "38. Use of strong motivators". Guided by the TRIZ expert, the group interpreted "change the density" as extra-money, extra-effort, bonuses. "Change degree of flexibility" was interpreted as periodicity, as well as learning using internal case studies. "Strong motivators" was interpreted as use of internal professionals for some support. After consolidation of ideas, the proposed solution was: Select two highly professionals from the company and ask them to perform periodic training to the ten people. The two internal trainers are paid per hour for this extra-effort at a superior hourly rate than their usual salary. The training is directed towards the specificity of the projects within the company.

For the second exercise, under the close guidance of the TRIZ expert, the second group generated the problem in the form of two pairs of conflicts: "9. Speed to execute the task" versus "10. Involved engagement in the task" and "9. Speed to execute the task" versus "19. Effort to motivate dynamic elements (e.g. persons)". The subsequent inventive principles are: "13. Inversion or reversion", "28. Replace the traditional system", "15. Dynamicity", "19. Periodic actions", as well as "8. External support", "35. Transformation of system properties" and "38. Use of strong motivators". The group had to deal simultaneously with seven inventive principles. No clue on the most appropriate inventive principle where to focus attention for problem solving was reported by the group. However, under the guidance of the TRIZ expert, the group proceeded to a creative association of the inventive principles. The results are: turn the system "upside-down" ≡ incentives for prompt communication; replacement of a traditional system by a softer system ≡ implement a software solution for information management; divide the system into elements that are able of changing their position relative to each other ≡ responsible persons to improve communication; periodic action ≡ frequent remembering to improve communication; compensate for the weakness of the system by interaction with supporting "forces" coming from an outside environment ≡ frequent; change the conditions ≡ change the mode of communication; change the concentration of the state ≡ well-defined channels of communication; use strong "motivators" ≡ warning for possible cuts of "freedoms". Ideas have been further consolidated into the following solution: The assistant manager will send two messages/days to alert people for disseminating information to those envisaged (using a group address on Yahoo messenger and MS Outlook (e.g. team@xxxx.com). This means people will have officially access to Yahoo messenger at work. After some repeated messages, employees might change their behaviour just to stop these annoying practice. In addition, an official mode for storing and disseminating information will be imposed (e.g. electronically, using CVS

application). Also, people will be warned that if the problem of prompt communication is not remedied, the access to Yahoo messenger and Internet will be blocked for all employees.

For the third exercise, the group guided by the TRIZ expert formulated the problem in the following way: “10. Involved engagement” versus “15. Durability in time of dynamic elements”. The related inventive principles are: “19. Periodic actions” and “2. Extract, retrieve or remove some elements from the system”. Under the guidance of the TRIZ expert the creative process of translating these principles into concrete ideas led to the following results: increase frequency of periodic impulses ≡ one criterion for salary increasing is direct related to the level of support appreciated by her/his colleagues; extract, remove or separate a “disturbing” element (unit) or property from the system ≡ mixed teams, focus on team results and salary bonuses based on team productivity. Thus, the end solution was: team-related salary bonuses and salary renegotiation based on 360° assessment of support-related issues between the team members.

The conclusion extracted from the results and discussions with the second group is that the presence of a TRIZ expert helped a lot in proper application of TRIZ. However, if the TRIZ expert is not a professional in the problem domain, it cannot substantially contribute to the formulation of the final solution. It is like the case of coaches and sportspersons.

The third group was asked to apply the SAVE technique to solve the three exercises. The first exercise is further illustrated. According to SAVE, it starts with the definition of the target result, that is: all people to be trained in technology X without additional costs from the company. The system at start comprises 10 unskilled persons and 5 professionals in technology X. Application of SAVE vertexes is presented in continuation. V1 (activate resonance) automatically directed the group to the idea of putting somehow the 5 professionals for training the 10 unskilled colleagues. This vertex immediately conducted the team towards a similar solution with the one proposed by the second group, which was guided by the TRIZ expert. To refine the idea, V2 was further applied. V2 (introduction of neutral elements) immediately indicated that the solution should be towards elimination of the negative attitude of the group of 5 professionals by showing them a new perspective. Thus, the solution was to discuss with each of the 5 professionals to cover each of them 20% of the training program using materials from existent projects. After training, each of them will coordinate 2 of the beginners in a forthcoming project where bonuses will cover the cost of the extra-effort done by the group of professionals. In principle, the group decided this is the solution they have to consider. It is very close to what the second group proposed. However, considering further the vertex V3 (anti wolf-pack spirit), the group saw a good alignment of the already proposed solution with the line suggested by this vertex, which asks for solving the problem with no external support or with external support, but voluntarily. In fact, a closer investigation of this possibility revealed to the group that it might happen to be other training programs run by universities or cluster initiatives in some projects financed from public funds where such trainings to be for free or cost affordable. In conclusion, no further effort to refine the solution was considered necessary.

For the second exercise, the target result was formulated as: quasi-instantaneous dissemination of information between departments. The system at start consists of all employees, the electronic communication means and the organisational structure. Application of V1 (activate resonance) led to the idea of showing quantitatively the losses in productivity of each department, losses in business opportunities, as well as negative effects on customer satisfaction, caused by delays in internal communication. This action is expecting to change the perspective of people about the situation and properly modify their behaviour. However, to strengthen the solution, application of V2 (introduction of neutral elements) led to the idea of showing people the implications of the status-quo on their salary and which would be the positive effect on salary growth if productivity would reach a certain level. The idea was that communication problems are not caused by people’s laziness, but by their disconnection from the business processes, as well as the lack of performance management in the company. V3 (anti wolf-pack spirit) was further considered. It led the group to the idea of encouraging every people in the company to express monthly his/her satisfaction/dissatisfaction in relation with the promptness of getting the necessary information from colleagues. By making visible this situation, it was expected people would change behaviour in the right direction. To consolidate solution, V4 (activate centrifugal forces) was also experimented. This vertex inspired the group with the idea of announcing people that if the situation will not be improved, a reengineering of the whole organisational structure will be tackled. In principle, people are concern of changes. They prefer a kind of status-quo because they understand the current mechanisms and know how to construct their patterns of survival. Any new major change is not desirable, especially by those that have good positions in the company. This potential perspective is expected to change the situation by motivating the heads of departments to take measures at their initiatives. To consolidate the system, V5 (multi-level connectivity) was further applied. It encourages to enhance collaboration between various levels of execution and decision in the company. From this perspective, the group was inspired to propose an internal survey in the company such as to identify shortcuts of communication at every level. Results will be further implemented, thus eliminating part of bureaucracy. The group was satisfied with these transformations in the system and decided to stop ideation at this point. The group appreciated that the package of interventions are enough robust and further transformations would be justified only if, after the implementation of the suggested interventions, things will not reach the expected target.

The third exercise conducted with SAVE started from the following target result: beginners should reach a productivity and quality levels that are not less than 20% of experienced staff. The system at start comprises the beginners, the experienced staff and the way they are organized. The first vertex V1 (activate resonance) asks to put beginners in the shoes of experienced staff and vice versa. From this angle, the problem was seen by the third group as a form of natural

manifestation of human consciousness, which call for energy conservation and sense of security. It was concluded that the problem can be solved if the "resonance frequency" of both categories of stakeholders will be moved in other position and interests will be synchronized. The solution proposed by the third group is to organize teams of two persons (a professional and a beginner), with difficult tasks allocated to beginners and with responsibilities given to professionals to meet time and quality targets, conditioning salary (bonuses or penalties) of the team by meeting these targets. V2 (neutral elements) led to the idea of correlating annual salary increase with team work performance and proof of its contribution to business profitability. Application of V3 (anti wolf-pack spirit) conducted to the idea of conditioning project allocation and related bonuses to each team by the previous performance of the whole team. If teams are of the same value, allocation will be conditioned by additional criteria, related to innovativeness brought in the previous projects. Application of V4 (centrifugal forces) revealed that further improvements are necessary to avoid potential risks, such as professional staff turnover. This issue indicates a need for organizational changes, such as the creation of several positions of Black Belt masters whose responsibilities are to move to different teams and work shoulder-to-shoulder with them, as well as support them for keeping the project in budget, time and quality, and also to improve individual performances. Professionals with be asked to assess beginners and to propose individualized training programs. This task will reveal many hidden issues and tacit knowledge.

An important conclusion from SAVE application is that solutions cannot be formulated away from stakeholders, which have to apply them or will be affected by. This is a crucial finding and a key element to succeed with SAVE. This means, at every step of SAVE, a feedback is necessary from stakeholders. This let the team to understand better the level of gap with respect to the target result and calibrate solution. The second finding is that, in most of the cases, there is no need to apply the whole set of vertexes proposed by SAVE to identify an innovative solution. The third finding is that the SAVE technique is strongly convergent. After each iteration, solution is not deviated, but rather consolidated. This reflects the effectiveness of the order in which vertexes are applied. The fourth finding is that SAVE leads to solutions that are close to those formulated by experienced TRIZ-driven teams. This encourages to consider SAVE as a reliable alternative to more elaborated tools for approaching non-technical problems by usual people. The fifth finding about SAVE is that this technique does not raise difficulties for application and more than this, it helps people to think non-linear in a natural way. This aspect reflects a strength of SAVE in relation with the challenge envisaged in the case of TRIZ application by non-experienced people.

5. Conclusions

The main contribution of this paper is about revealing new perspectives of human behaviour in the process of creative problem solving, as well as the proposal of a new technique called SAVE that would positively contribute to the guidance of less experienced people towards non-linear thinking in the process of ideation.

In order to analyse the potential of SAVE, an experiment was conducted having as reference an already proved tool for its potential in inventive problem solving, namely the basic method of TRIZ framework. The proposed experiment confirms what other researchers concluded in terms of TRIZ application by beginners. Also, it shows a good potential of SAVE in creative problem solving and encourages its future application in various managerial projects. At this stage of development, SAVE was envisaged for non-technical problems and there is no idea about its potential in the case of technical problems. This would be a niche for future investigations. Nevertheless, consolidation of the SAVE's perspective as an effective tool for creative problem solving requires time and a critical mass of solved projects. This is another area of research that relates with SAVE.

However, it is already know that in a complex, non-linear and adaptive system, as our world is, there are no optimal solutions and no ideal solutions. Even TRIZ masters talk about local ideality in relation with inventive problem solving, stressing the fact that solutions are in close relation with the wideness of the problem to be solved. As long as even TRIZ algorithm works with formulation of mini-problems, it is hard to envisage that local ideal solutions would not affect other parts of the wider system or would not unbalance somewhere or somehow the system. Therefore, a wise approaching of intangible complex systems is by considering more mechanisms and paths of investigation. Sometimes, all paths lead to similar or close solutions. Other times, hybridization of solutions emerged from different paths is the right resolution of a given problem. From this perspective, there is enough room of manifestation for SAVE technique, as well as of many other tools of creative problem solving.

References

[1] Rantanen K, Domb E. Simplified TRIZ. New problem solving applications for engineers and manufacturing professionals. Boca Raton, USA: Auerbach Publications/CRC Press, 2010.

[2] Savransky SD. Engineering of creativity. Introduction to TRIZ methodology of inventive problem solving. Boca Raton, USA: CRC Press, 2000.

[3] Ilevbare IM, Probert D, Phaal R. A review of TRIZ and its benefits and challenges in practice. Technovation 2013;33(2-3):30-37.

[4] Nakagawa T. USIT operators for solution generation in TRIZ: clearer guide to solution paths. ETRIA TRIZ Future, Florence, 2004; 347-363.

[5] Reich Y, Hatchuel A, Shai O, Subrahmanian E. A theoretical analysis of creativity methods in engineering design: casting ASIT with C-K theory. J Eng Design 2012; 23(1-3):137-158.

[6] Root-Bernstein R, Root-Bernstein M. Sparks of genius. The thirteen thinking tools of the world's most creative people. Boston, USA: Houghton Mifflin Co., 1999.

[7] DeBono E. Six thinking hats. London, UK: Penguin Books, 1987.

[8] ***. All creative tools. http://creatingminds.org/tools/tools_all.htm, accessed June 10, 2016.

[9] Altshuller G. TRIZ keys to technical innovation. Worcester, USA: Technical Innovation Center, 2002.

[10] Carter T. An introduction to information theory and entropy. Complex Systems Summer School, Santa Fe, June, 2011.

Tech-Finder: a Dynamic Pointer to Effects

Davide Russo* [a], Tiziano Montecchi [b], and Antonio Caputi[a]

[a]*University of Bergamo, viale Marconi 5, Dalmine 24044, Italy* [a]

[b]*Bigflo srl, via Galvani 2E, Dalmine 24044, Italy*

* Corresponding author. Tel.: +39.035.205.2353; fax: +39.035.205.2077. *E-mail address: davide.russo@unibg.it*

Abstract

The dynamic pointer to effect is an IR tool that searches for a scientific effect capable of providing the required function. At difference from static pointers which are entirely pre-built databases, the dynamic type is based on the integration of a pre-built effects library with a semantic search engine that scans technical and scientific literature in order to suggest documents describing relevant effects to realize a certain function. As result, the search engine can use any function in form of a pair verb-object, where the relations between functions and effects are always updated with the updating of the literature and the suggested list of effects is always tailored only on the specific function of the user, avoiding huge lists that make the tool unusable for low precision. The key aspect of the dynamic database is that recall and precision problems can be decoupled, in fact, recall depends on the completeness of effect library and the expansion of the query, while precision is affected by the IR algorithms of the search engine. The present article presents a comparison of the most representative pointers to effects (developed by Altshuller and later) together with an analysis of the open problems and main limitations of these tools shown on three case studies selected in order to bring out the main limitations of effects databases.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Pointer to Effect, Effects Database, Patent, Technology Transfer, State-of-the-Art

1. Introduction

It is opinion of many that TRIZ is characterized by two peculiar aspects which are not present in any other problem solving method: (1) TRIZ is based on the axiom stating that technical systems evolve on the base of objective laws. Such laws, which are intelligible, may be identified and finally utilized in order to solve inventive problems consciously. (2) all systems grow according to the increase of contradictions. The quantity of contradictions rises, and their solutions are achieved as consequence of a quality gain, or, in other words, thanks to the introduction of a completely new idea. The fundamental condition to "know" an object, to represent its nature using ideal images, is the knowledge related to the "whole system of contradictions", that even V.I. Lenin had described before as the determination of a concept passing through the contradictory nature of the thing itself, the contradictory forces and tendencies in each phenomenon.

However, aside of these two aspects, there is another important feature which is not normally highlighted as it should: TRIZ may be deeply integrated with several structures for the organization of knowledge, as inventive principles, guidelines, evolution trends, and, most important, physical, geometrical and chemical effects Dbs.

It is quite simple to understand that the introduction of "philosophical" and evolutionary perspectives are unique concepts in the landscape of problem solving methods, while it is very emblematic that no other method, except for TRIZ, has developed knowledge databases which are transversely useful to anyone who needs to solve a problem.

Outside the TRIZ, in the last 10-15 years, web portals increased in number and diffusion, and many have been

developed in order to allow the access to a growing number of Dbs, mostly containing technical information about materials. More in detail, specialized sites are more than 40 focused on different types of materials: metallic, ceramic, plastic, glass, eco-sustainable, thermal, chemical, textile, nanocomposites, semiconductors, crystal structures and others. Further examples are sites organizing information on the base of the application field, such as architecture, additive manufacturing, optics, and many other fields of engineering.

Moreover, great interest comes from the recent rise of repositories of "natural solutions" inspired by the biological world. Although more than 40 years ago, TRIZ already predicted the potential of such approach to support the design by analogy, only recently remarkable portals have been developed (i.e. Asknature, Biomimicry, Dilab).

Regarding Dbs of geometric effects, the last relevant work is dated last 80's, more precisely the Vikentiev's article "In rules of a game without rule" [1]. In such a work, different objects are classified according to the way their shape influences their behavior, in order to generate some specific function or physical effect. Even for what concerns the chemical effects, very few sources of information can be found; an example is given with Salamatov's study [2].

Finally, we report on the Dbs of physical effects. Such Dbs hardly caused an interest in the scientific environments, with the exception of TRIZ community, which has deeply investigated them, before and even after the Altshuller's death.

Next section presents an introduction of effects Dbs together with a review of a selection of 5 Dbs available in literature. The third section is dedicated to compare these Dbs and highlight their main limitations using three different case studies. In the last section, conclusions are drawn.

2. State of art on Pointers to Effects

The goal of Pointers to effects (also called effects databases) is to simplify the search of a physical or chemical effect, factor, or method capable of providing the required function or property. From the point of view of simplicity of effects application, the database of effects is built on a functional principle: it contains a list of functions (applications) commonly encountered in practice, and a corresponding list of effects that may be employed to realize these functions. This structure helps engineers to resolve technical problems. For all of Dbs, procedure is the same:

- Define what function you want to achieve in your product/system.
- Select, from the list of functions, the function which is closer to what you defined as your desired function. Then select the object or attribute of that function.
- The database extracts a list of physical effects and phenomena which can be used as physical principles to deliver the selected function.
- Visualize the information about the selected effect or phenomena, in some case equipped with examples, case studies, patents, images and formulas.

The main differences stand in the quantity of physical effects considered, and the strategy to use them. The present paper takes into account only a selection of the most known and representative portals. For example, the authors do not consider Dbs in Russian language, because they are not particularly relevant in terms of number of effects. Even the original list of effects of Altshuller is not reported, since further versions enlarged by his disciplines have been preferred because more complete and organized, such as the Korean web portal realized under the supervision of Nikolay Khomenko (Triz.ko.kr).

Regarding the comparison with commercial software, Tech optimizer v. 3,0 have been chosen, which is provided with the same effects library as the more famous Goldfire. Whereas, we consider its functioning for what concerns the semantic research. Moreover, two software have been taken as reference, since they are of recent conception, and due to the diffusion of internet and open source philosophy: Oxford Creativity and Production Inspiration of Aulive (connected to Creax).

Finally, Tech-Finder is presented as the new tool developed in collaboration with the University of Bergamo.

For the comparison, three different case studies have been properly selected in order to show the main limitations of effects Dbs, these are reported in the following:

1) in order to improve a product or an object, the functional decomposition of the same may be a critical passage, because the MUF (Main Useful Function) may be expressed in many ways, according to the level of detail of the description, or the function may be referred to different (but equivalent) objects (for instance, "sterilize vessel" is conceptually equivalent to "kill bacteria");
2) the definition of the function is not trivial, due to the problems of polysemy, the same term (verb) may specify many different functions (for instance, the term "separate", may be interpreted as "disconnect", "divide", "discharge" or "extract/remove");
3) there is not a unique and common library of physical effects, as well as, a definition of physical effect unanimously accepted in literature. Thus, each Db has its own library, leading to a proliferation of many different libraries that in some cases are not updated.
4) there is not a proven way to suggest physical effects. The way of providing and visualizing the trigger result changes from software to software (from simple list of effects to detailed explanations, images, formulas, applications, patents, etc.)

The authors, propose an analysis (see table 1) of 5 Dbs based on four features that we explain in the following to facilitate the understanding of the analysis:

- Query: is the input of the Db, and it coincides with the functions which are the way of using these Effects known to the database.
- Effects: are the result of the database depending on the query.
- Relation: link between query and effects, in case of a database is a linking table that holds the many-to-many relationships between Queries and Effects.
- Type of database: in this article, the authors divide the DBs in two types, static Dbs using a prebuilt database with pre-

set queries, effects and relations. Dynamic Dbs are based on a pre-set library of effects, while queries are any available functions and relations are created from time to time by a search engine that retrieves documents linking that function with the effects.

Table 1 Pointer to Effect comparison

	Altshuller Db/ (Triz korea)	Tech-Optimizer 3.0	Oxford creativity	Aulive	TechFinder
DB Type	static	static / (dinamic in Goldfire)	static	static	dynamic
Number of Effects	130 (approx)/ (141)	600	936	300 (estimated)	163
Number of query (function and attribute search):	30 /(51)	216	441	148	∞
Number of relations	224 /(398)	6500 (estimated)	19693	1000 (estimated)	∞

2.1. Triz.ko.kr - Altshuller Pointers to effect

Altshuller Pointers to effect in the latest version proposed by Savransky [3] is a static database containing a limited list of very general actions (e.g. measure, move, formate, etc.) commonly encountered in practice, and provides three types of object (solid, liquid, gas). Definitions of effects are not precise (e.g. Thermal-electrical phenomena, Electro-hydraulic effect), no effects description is available and the Db is not kept updated. A larger and updated version has been proposed by TRIZ Korea (http://www.triz.co.kr). The number of results for each query stands in a range between 2 and 30, and normally are in the form of "verb" and "object", and possibly a "parameter". The visualization of results contains the effects description, and in some cases images and formulas.

2.2. Tech-Optimizer 3.0

It has been conceived as a stand-alone software for supporting a creative thinking of engineers and researchers inside a more ambitious projects combining artificial intelligence with the theory of inventive problem solving [4, 5]. From 1999 to 2010 Tech-Optimizer was a part of Goldfier Innovator by Invention Machine. It works in a static way but together with Knowledgist + CoBrain, the Semantic processors retrieve "grains" in a dynamic way from patent literature or preprocessed knowledge based. A detail explanation about Tech-Optimizer functioning is offered by Nakagawa paper [6].

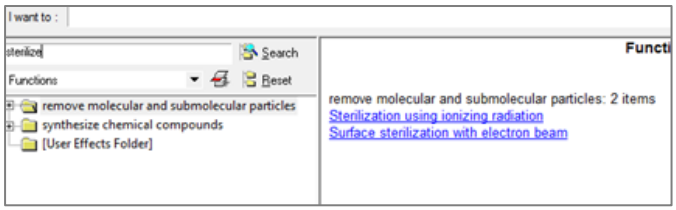


Figure 1. Tech-Optimizer 3.0: screenshot of input and results classification

There are two main modes of searching inside the Db:

- "Functions Groups" consists of browsing effects that are categorized in two hierarchical levels: general functions performed on field, parameter and substances (example of functions "accumulate", "detect", "prevent", etc.) and sub-functions (example of sub-functions of "accumulate field": "absorb electromagnetic waves or light", "absorb forces, energy and momentum", etc.).
- "Search" consists of a keyword search on effects titles and descriptions. The effect is retrieved only if the query exactly matches the text.

2.3. Oxford creativity

TRIZ effects database provided by Oxford Creativity (https://www.triz.co.uk/triz-effects-database) and presented by Martin [7] offers (as of May 2016):

There are three main modes of operation in order to consult the Db: Function, Parameter and Transform:

- The "function" mode, allows to select one of the 175 queries, which are generated by the combination of 35 verbs (e.g. "absorb", " accumulate", " bend",…) and 5 objects ("divided solid", "solid", "liquid", "gas" and "field").
- The "parameter" mode, is advantageous when the request is to modify a specific technical parameter. The Db allows to formulate 185 queries, combining 37 parameters (e.g. "brightness", "color", "concentration",…) and 5 basic verbs describing the desired modification (e.g. "change", "decrease", "increase", "measure", "stabilize").
- Finally, if the goal regards the transformation of energy, 9 forms are available as input and output (e.g. acoustic, chemical, electrical energy, etc.), so it is possible to formulate 81 queries.

Figure 2. Oxford Creativity: screenshot of input of the "function" mode

Regarding the visualization, usually queries produce an average of 50 effects and applications. Results are presented as a list of suggested Effects and Applications, each of which is linked to a short description of the effect and, in some cases, a short application note. Most of effects and applications are linked to a definition page of Wikipedia or other web resources.

2.4. Production Inspiration

Production inspiration is an effects Db by Aulive (http://www.productioninspiration.com/), it provides (as of May 2016). The queries are the composition of 37 functions over 4 different objects ("solid", "liquid", "gas", "field").

Regarding the results and their visualization, usually queries produce from 1 to 20 effects, which are explained by using an animation of an applicative example, a brief description and the explanation of a case study.

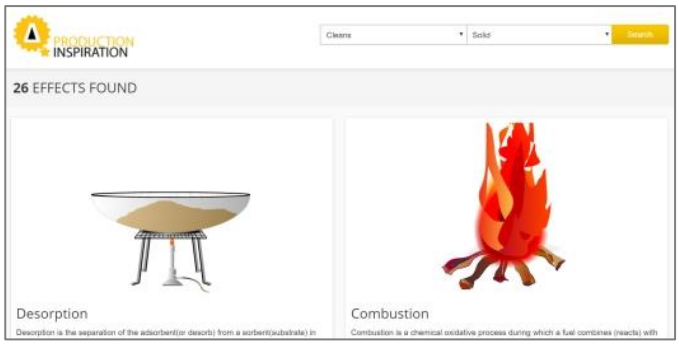


Figure 3. Production Inspiration of Aulive (Creax): screenshot of input and resulting effects

2.5. Tech-Finder

Tech-Finder is a dynamic effects database developed by BiGFLO in collaboration with the University of Bergamo [7].

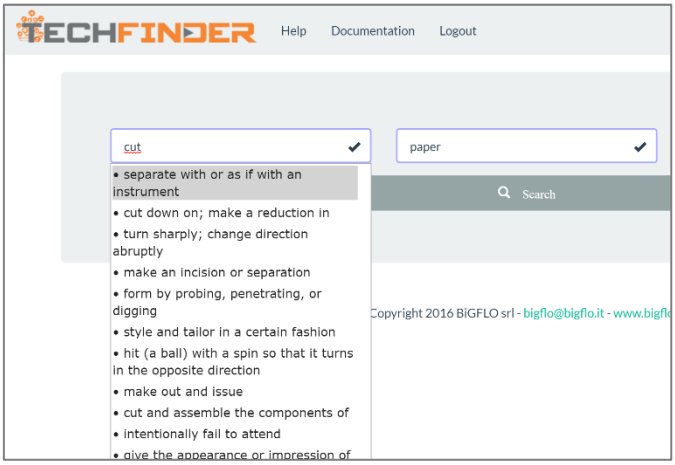


Figure 4. Tech-Finder: screenshot of semantic input. Verbs and objects are not chosen from a predefined list.

The software works with any query in form of a pair: verb-object: these terms are conveniently "expanded" (in order to improve the recall), and the semantic engine carries out a search on technical or scientific literature, such as patents and internal knowledge bases. The result of such procedure is processed using a (static) set of more than 150 physical effects, so that the relation between query and physical effect is created. The link between query and effect is the patent document (or any other kind of documentation) and this relation is created only if the use of the physical effect to perform the function (query) is described at least in one patent of the domain. The output consists in a list of physical effects, which satisfy specific semantic relations occurring between the search terms in the query, and the searched effects. The number of provided effects changes according to the specific query, so that the pair "sterilize" and "lens" will produce a different result compared to the pair "sterilize" and "surface", or "sterilize" and "solid" [8, 9].

In a dynamic pointer the quantity and quality of results depends on the nature of the data source. Patents have been selected because, even if their content may be sometimes misleading regarding the object of the patents themselves, the control provided by examiners ensure the accuracy of the description of the physical processes reported anyway; moreover, the number of patents (more than 90 millions), and the variety of fields treated makes such data source very interesting.

The visualization of results is provided by visualizing the physical effects classified in five fields, according to M-A-T-Ch-EM scheme; furthermore, there is the possibility to visualize the more pertinent patents, potential technological trends, possible competitors and related infographics.

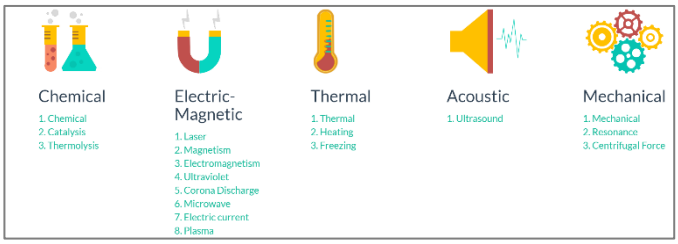


Figure 5. Tech-Finder: screenshot of effects classified according to MATChEM

3. Case studies

Three case studies have been selected from a pool of many real professional activities: the choice depends on the request of the customer to investigate completely new operating principles for their products, introducing new physical effects.

Cut paper: "to cut" is a very precise indication, mostly without homonymies, and the noun "paper" makes the function not compatible with most of physical effects.

Reduce noise: this test is done in order to search features in a domain which is well known, but generally not enough covered from effects Dbs.

Sterilize lens: the query is very relevant, and, moreover, functional analysis may be set up using different couples of terms for the verb and the object ("sterilize" and "lens", "kill" and bacteria", etc.). This particular case study is ideal in order to test the Dbs because the authors have already built an exhaustive patent collection related to contact lenses sterilization which has been already classified into physical effects by a manual selection [8]. This pool, called "Sterilization Pool", has been updated and it contains around 1300 patent families only with English text and obtained from the IPC patent class (A61L12: Methods or apparatus for disinfecting or sterilising contact lenses; Accessories therefor). Each document has been manually classified according to

physical effects used to setrilize. The final result is a list of 22 physical effects, subdivided according to the MATChEM as shown in Table 2.

Table 2. List of 22 physical effects manually found inside the Sterilization Pool and classified according to MATChEM

PHYSICAL EFFECTS		
MECHANICAL	**CHEMICAL**	**ELECTRO-MAG.**
1. Centrif. force	9. Catalysis	17. Gamma radiat.
2. Pressure	10. Electrolysis	18. Laser
3. Vibration	11. Chemical general	19. Led
ACOUSTIC	**ELECTRIC**	20. Microwave
4. Ultrasound	12. Corona discharge	21. Plasma
THERMAL	13. Electric current	22. UV light
5. Boiling	14. Electrophoresis	
6. Freezing	15. Electron beam	
7. Vaporizing	**MAGNETIC**	
8. Heating	16. Magnetic field	

Figure 6 presents the comparison of results for the three case studies. The first one was about the lens sterilization. Relevant effects, recall and precision are calculated in relation with the 22 effects manually identified inside the Sterilization Pool (Table 1). These 22 effects are considered the total number of effects available to sterilize contact lenses, thus if a Db suggests all these 22 effects it reaches 100% of recall.

Since the primary purpose of an effects database is to provide knowledge of relevant effects, recall value is the most important index. In this specific case study, among all the static Db, Oxford creativity reaches the best recall.

As we can see, the compromise for having a high recall (54%) is to suggest a huge list of effects for each query, this often leads to report many irrelevant effects (low precision, 14%). We can observe the same behavior with Tech-Optimizer, which has high recall (41%) but very low precision (5%). This contradiction between recall and precision of static Dbs can be overcome through dynamic Db that, for every query, searches all the effects of the library, selecting from patents only those that are really relevant for the query/application field.

The case study about cutting paper, shows the general inefficiency of pointers for this kind of application. Most of tools are capable of providing a large number of effects but unfortunately many of them are not relevant and at the same time the most widespread and known are missing (i.e. laser cutting, water cutting, etc.). One of the main reason to explain that resides in the fact that “ to cut” is not present. Using “separating something” instead of “cutting” produces a list of effects more related to the meaning of “ differentiating one solid to another one” that cutting it.

In order to solve this problem, it is not sufficient to move from static to the dynamic database, but it also necessary a semantic search engine.

Finally the case about reduce noise. Altshuller’s list of effect doesn’t allow to translate the problem into any functional query. The other pointers provide a short list of effects, all related to sound domain but not applicable to noise reduction. It seems this topic conceived for describing a phenomenon instead of using the suggested effect for solving a problem

4. Conclusion

Existing pointers to effects can be divided in static and dynamic according to the way the query can be built.

Until now only Goldfire was able to provide a dynamic pointers even if its kernel was based on a static database as Tech Optimizer.

In this work a new dynamic pointer of effect, called Tech Finder is proposed. It allows the user to insert a specific function without worrying to convert it in a preset query, suggesting effects always tailored to the specific field of investigation and supporting idea generation by a sample of patents or other documents describing the application of that effect to the specific user function.

While the benefits provided by a dynamic pointer are countless, the other we have a much more complex tool, whose effectiveness depends on the richness of the knowledge base and effectiveness of research strategies and search engine to

overcome problems of homonymy, polysemy and effects interpretation.

.TechFinder works on patents and has integrated both language filters for semantic disambiguation and typical filters from patent search engines (such as the IPC code for patent classes identification).

Indeed, a specific library for searching effects have been developed including technologies and units in the list of keywords used for expanding the concept related to all effects to be searched.

In addition, the classification of scientific effects according to MATChEM fields enhances also the capability of integration with other TRIZ tools (e.g. 76 Standard Solutions).

Finally, the dynamic pointer can be easily used for several purposes such as state-of-the-art, technology transfer and idea generation activities, just playing on the abstraction level of the function (e.g. sterilize-lens, sterilize-surface, clean-object).

Pointers Comparison		*Altshuller*	*Tech-Optimizer*	*Oxford*	*Aulive*	*Tech-Finder*
STERILIZE LENS 	Results Relevant/Tot	4 /15	9 / 173	13/96	6/26	18/22
	Recall	17 %	41 %	54 %	27 %	75 %
	Precision	27 %	5 %	14 %	23 %	82 %
	Query	• destroy object: 11 • purify substance: 4 *Many inappropriate effects, e.g. cutting by water, laser, mech., Coanda effect, etc.*	• clean solid substances: 30 • destroy substances: 22 • destroy tech. objects : 9 • remove solid sub: 11 • remove molec. parts: 22 • remove particles: 32 • remove solid subst.: 57	• clean solid: 90 • purify solid: 27 *Function mode has been used*	• clean solid *20 effects may be relevant even if hardly applicable to the lens field.*	• Sterilize lens *3 irrelevant effects + 1 very general effect (thermal)*
CUT PAPER 	Results	22	99	188	16	18
	Precision	*Only ultrasound is relevant*	*Most of effects are irrelevant because not applicable to the function cut*	*Most of effects are irrelevant* (39 duplicates removed)	*The most common effects are missing, e.g. laser, water jet, plasma cutting,*	
	Query	• change objects size: 6 • separate substance: 16	• separate particles: 63 • separate solid substances: 44	• Separate solid: 115 • Break down solid: 112 *Function mode has been used*	• separate solid *"separate" is "differentiate one solid from another solid."*	• cut paper
DECREASE NOISE 	Results	0	26	12	8	28
	Precision	*There is not query related to acoustic*	*Most of effects describe the phenomena of sound without explain how to reduce it.*	*Most common effects suggested by other Dbs are missing. Most of effects describe the phenomena of sound without explain how to reduce it.*	*All effects are irrelevant with the noise field (e.g. Birefringence, Prism, Aerosol, Battery, Capacitor, Corona Discharge, Fly-wheel, Fuel-cell).*	
	Query	• No query	• Absorb mechanical and sound waves	• Decrease sound *Parameter mode has been used.*	• Absorb field: 6 • Remove field: 2 *It is very challenge to choose the appropriate function describing this case.*	• Decrease noise

Figure 6 Software comparison on 3 different case studies

References

[1] Vikentiev I.L. About using geometrical effects in the inventive problem solving process*; In rules of a game without rule, S. Petrozavodsk: Karelia*, 1989. ISBN 5-7545-0108-0

[2] Salamatov, Y.P. Heroic Deeds at Molecular Level: Chemistry Helps Solve Difficult Inventive Problems. - A Thread in the Labyrinth / Compiled by Selyutsky, A.B. - Petrozavodsk: Karelia, 1988.

[3] Savransky SD. Engineering of creativity: introduction to TRIZ methodology of inventive problem solving. 2000. Ed: Boca Raton, Fla.

[4] Kucharavy D. Thoughts about history of Inventive Machine Projects, Presentation at LICIA / LGECO - Design Engineering Laboratory INSA Strasbourg, 2011. http://www.seecore.org/d/20110923(2).pdf

[5] Tsourikov V.M., Inventive machine: Second generation. AI & SOCIETY, 1993. 7(1), pp.62-77

[6] Nakagawa T., Software Tools for TRIZ - Mechanism, Usage, and Methodology Learning -- Invention Machine's TechOptimizer Pro Version 2.5, 1998.

[7] Martin A. Brewing Free Beer: Using Ideality to develop a 'free-to-use'TRIZ Effects Database. Procedia Engineering. 2015 Dec 31;131:312-26.

[8] Montecchi T., Russo D. Dynamic and Semantic Database of Effects for Technology Transfer. Innovator: Journal of the European TRIZ Association. 2016. ISSN 1866-4180

[9] Russo D, Montecchi T, Liu Y. Functional-based search for patent technology transfer. In ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference 2012 Aug 12 (pp. 529-539). American Society of Mechanical Engineers.

[10] Montecchi T, Russo D. FBOS: function/behaviour–oriented search. Procedia Engineering. 2015 Dec 31;131:140-9.

The Application of TRIZ to exclude Product Failures caused by unintended Operation Errors

Jürgen Heß

BSH Home Appliances Group, Wohlrabedamm 15, 16329 Berlin

Tel.: 49-30-81402-2725; fax: +49-30-814025010. *E-mail address:* juergen.hess@bshg.com

Abstract

Products that are obviously robust against unintended operation errors fulfil one basic requirement for being economically successful. This article concentrates on the TRIZ supported treatment of product failures which are caused by unintended operation errors. An effective approach to counteract unintended failures has been introduced for production processes, known by the Japanese expression Poka Yoke. Synergies between the Poka Yoke approach and TRIZ are highlighted and discussed. Based on typical patterns of operation errors by end-customers a general proceeding is worked out. Special emphasis is paid to the identification, the comprehension and the counteraction of failures caused by unintended operation errors.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: TRIZ, unintended operation errors, failure safe products and processes, Poka Yoke, failure reproduction,

1. Introduction

According to the commonly accepted model in TRIZ the product cycle can be classified into several phases, figuratively characterised as pregnancy, childhood, growth, maturity and decline [1,2,3]. This development of the product is described by the S-curve. Each of these phases shows its characteristic type of failures and typical procedures to counteract theses failures. Reliability statistics provides the classical failure types, as early failures, random failures and wear out failures [4,5]. During the growth and the early maturity phase, it has been observed, that the so called early failures provide the predominant contribution to the failure behaviour of a product in the field. Hence, in modern concepts for product development the elimination of early failures is in focus [6]. The following type of failures that becomes predominant in the time consecution is the so-called random failure. Wear-out failures occur in the later life of the system, ideally they are observed beyond the designed-in life time.

In the recent paper [7] it has been pointed out that there is a correlation between these failure classes are associated with typical cause and effect scenarios.

- Early failures were excluded from consideration. In the practical application, the root-causes for early failures can be identified in weak design, weak assembly or weak maintenance. In most cases the root causes for early failures are rather obvious and the counteractions straight forward.
- Random failures are targeted in this article. At least one link in the cause and effect chain is an occasional harmful obstacle, in most cases an external obstacle. In the practical life it is very often an unintended operation error by the customer.
- Wear-out failures occur in the later life of a system due to enduring harmful load or stress to the system. As previously mentioned, in well designed systems wear-out failures should occur after the planned minimum life time of the system.

Fig. 1 presents historic data of the failure rate of a typical

home appliance depending on the time to failure of the product. The typical bath type shape is obvious: Early failures dominate the early life-time of the system, later random failures provide the major contribution and the onset of wear-out failures is visible. About 60% of the observed product failures can be attributed to random failures. To our experience many random failures are associated with an unintended wrong operation caused by the end-customer, a so-called unintended operation error.

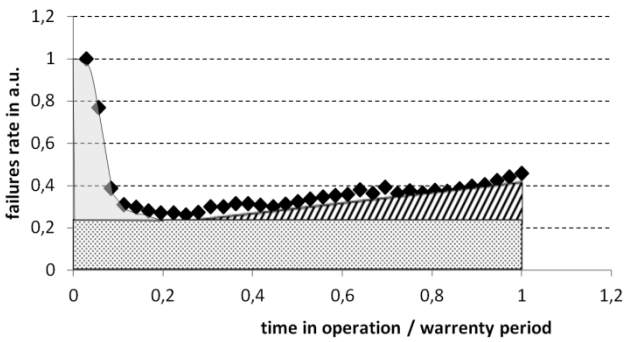


Fig. 1: Failure occurrence depending on time in operation for a typical home appliance versus the time in operation (grey: early failures, dotted: random failures and hatched: wear-out failures)

Many organisations tend to exclude end-customer's operation errors from manufacturer's compensation obligations. This purpose can be achieved by exclusions in the system specification or by special hints in the operation manual. Nevertheless, many end-customers do not entirely read the system specification or the operation manual. Furthermore, end-customer's action which is conforming to the specification or the operation manual requires end-customer awareness and vigilance. In many cases end-customers are not willing to accept their responsibility for unintended failures. These customers can be lost to competition. Therefore the requirement emerges that products must be robust against unintended operation errors.

2. The Poka Yoke Approach in Production Systems

Regarding unintended failures in production processes the analogue question was asked by the fathers of the Lean production system. It has become obvious that a main contribution to the losses in a production system was due to these unintended failures by the workers [7,8]. The target of the so-called Poka Yoke approach can be summarised as the exclusion of unintended failures during production by development or redesign of products and processes.

- The preferred Poka Yoke approach concentrates on the target to make it impossible that the root cause for any unintended failure occurs. This requires a profound analysis of the production system and a well evidenced investigation of the failure root causes. At the same time a well established Poka Yoke offers the advantage that this failure mode will never occur. This approach is called elimination of the root cause.
- An alternative approach accepts that the root causes for the failures still occurs. The product or the process is changed in a way that the consequences of the root cause will be certainly not the formation of a failure. This approach is called breakage of the failure chain.
- A minor preferred approach is to react immediately after the discovery of the failure in order to limit its consequences. This approach is called the reactive approach.

The Poka Yoke principle is a well established approach to exclude failures in the context of production systems.

Various TRIZ tools can be used to counteract insufficient, excessive and harmful functions in a system which is exactly the target of a Poka Yoke solution. Although the benefit of TRIZ application in the development of Poka Yoke solutions is obvious, surprisingly small traces can be found in the literature.

3. Fundamental thoughts about TRIZ supported Poka Yoke Solutions

There is an obvious link between Poka Yoke and classical TRIZ, the basic substance field diagrams (see fig. 2). In practically all production processes there is at least one object to be transformed (S1), at least one tool (S2) and at least one operating unit (for example a worker) that provides an interaction to the object (F) via the tool. In this model, the root cause for a failure can be the object, the substance or the interaction (field). In the case of a failure the causing element can be a missing element or an element that is not in an appropriate condition (too much, too less, too early, too late, under the wrong condition, etc.) (see fig. 2).

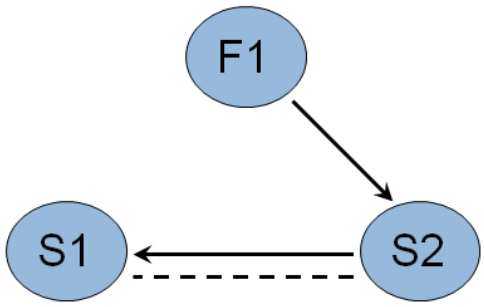


Fig. 2: Classical TRIZ picture of an element in a production process – the object that shall be transformed (S1) interacts with an operating unit (S2) which is provided by a field (F)

Fig. 2 demonstrates that the interaction between the tool (S2) and the object (S1) consists of a useful transformation of the object and a (permanently of occasionally) inadequate or harmful effect between S1 or S2. The inventive purpose is to counteract the harmful or inadequate effect. The purpose of TRIZ concentrates how fix the inadequate effect or how to draw off the harmful effect (dashed line in fig. 2) while maintaining the useful transformation.

The following solution approaches are possible and have to be taken into consideration:

- Complete substance field models can be achieved by the application of the standard 1.1.1 to 1.1.8. [8]. In terms of the problem this means concentration on the inadequacy. The inadequate element shall be transformed into an adequate one.
- Draw off the harmful effect is supported by the application of the standards 1.2.1 to 1.2.5. [8]. The harmful effect is eliminated from the system and consequently the failure vanishes.
- Detect or measure the causes of the harmful effect and react in appropriate way and react before the consequences become harmful. For establishment of a detection procedure the standards 4.X.X can be used [8].
- Prevent, separate or suppress the development of a failure caused by the harmful effect in the consecutive processes. The so-called harmful effect is still allowed to occur but its consequences shall be not anymore harmful.

The usage of the cause and effect diagram, as described by Terninko et al. [3] is at considerable extend advantageous. Fig. 3 displays two different states, in the first case (a) the nominal situation (no failure occurs) and in the second case (b) depicts the formation of the failure. It is obvious that the main difference is the unconscious transaction as the starting position of the failure formation.

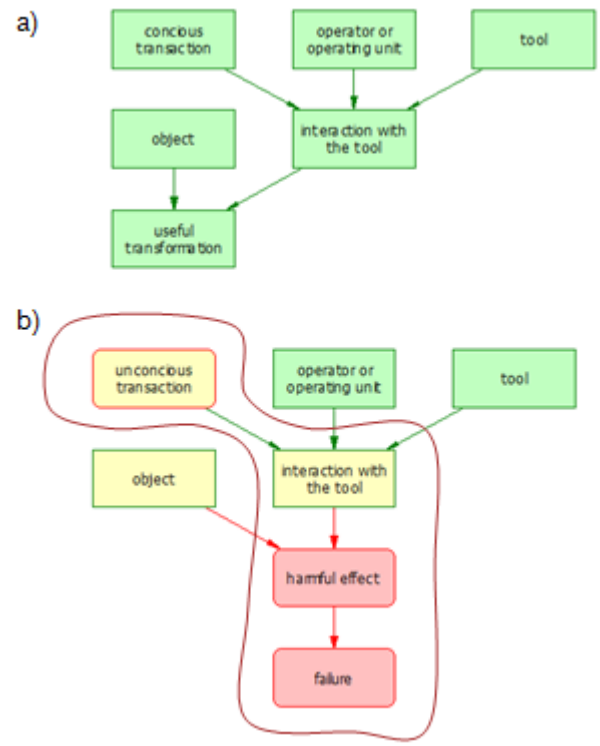


Fig. 3: Element in a production process in the cause and effect diagram – a) the nominal situation – production process step works as it is expected b) in the case of an unconscious transaction – if the process deviates considerably from nominal behaviour – the failure evolvement chain is encircled in fig. (b)

The advantage of the cause and effect diagram shown in fig. 3b is the fact that it depicts the basic contradiction which may lead to the Poka Yoke development. This contradiction can be summarised as:

- The interaction with the tool <u>must</u> be present to receive the useful transformation of the object.
- The interaction with the tool <u>must not</u> be present to avoid the harmful effect and consequently the failure.

The key condition for failures is the unconscious transaction by the worker. Unconscious transactions can be described as missing vigilance, for example caused by mental absence, misunderstanding, miscounting, forgetting, over-seeing or unnoticed impact by exterior disturbances.
The specified unconscious transaction and the previously defined contradiction depict a promising solution path for the application of the separation principles. The preferred solution shall be the elimination of the unconscious transactions, for example to ensure the conditions that the transaction will be performed always in the correct manner.

As an example a very common problem in mass production has been selected. It is obvious that worker's unconsciousness leads to a deviation between the position where the tool shall be applied and the position where it is in fact applied. A potential problem solution concentrates on the question how to separate in space that such a deviation cannot occur. An obvious solution is to fix the tool and the object in an appropriate manner, so that there is a unique motion of tool and object with respect to each other. In this context the object can be fixed using pilot holes in a fixture using slightly chamfered pilot rods at the same position pattern. If the tool describes a defined motion proper manufacturing can be ensured (see fig. 4).
Definitely there are alternative solution paths that may provide a solution. If the problem is formulated as a physical contradiction, our solution may appear. Furthermore, the consideration of standard solutions, system resources, physical or chemical effects may provide smart solutions.
For the sake of completeness it shall be mentioned that Poka Yokes are also applicable to prevent failures caused by variation of the input material and strange environmental conditions.

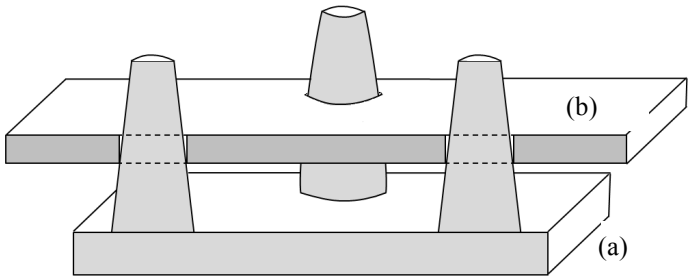


Fig. 4: A typical Poka Yoke in a production process to ensure the right position of a component in the machining process (a) fixture for the object with three chamfered pilot rods to determine the position of the object (b) the object with three pilot holes – the same pattern as the pilot rods of the fixture shall ensure proper positioning.

4. Failure Modes caused by the Interactions with the End Customer

From the first glance failure safe processes in the production and failure safe products in use by the end customer can be achieved by similar procedures. By consideration of the causes that provide a failure in production compared to the causes that provide a failure in the use by the end-customer there are some substantial differences.

- In a well organised production the processes are well established procedures. Workers are trained and well instructed. Wrong transactions, for example by missing information, are very unlikely to happen. For the same reasons harmful constellations will rarely occur. Harmful constellations cannot be excluded in the end-customer's environment. Additionally, it cannot be ensured that the end-customer has carefully read the operation manual and that he anticipates all the hints and recommendations described there.
- The tools used by the workers in a well organised production are purposefully designed for the operation. It cannot be excluded that the end-used either does not use tools, the tools are not appropriate for the intended transaction or the tools are not purposefully operated by the end customer.
- The production environment is well defined. In many cases environmental conditions vary in a well defined and well controlled process window. The workers are requested to fulfil distinct conditions regarding cleanness and order at their work position. The environment where the end-customer uses the product is not defined at all. Nevertheless, proper functioning of the product is a request.
- In a well organised production continuous maintenance is a well established procedure. Wear-out failures and failures which can be partly attributed to wear-out can be practically excluded. The producer cannot fully rely that the end-customer carries out product maintenance in the recommended manner in the recommended time sequences. Wear-out failures can be the consequence.

Therefore it is obvious, that failures cannot be attributed solely to the unconscious behaviour of the end-customer. Failures may be also the result of the fuzzy conditions of the product storage or usage. In reality a combination of both is a very likely scenario.

As a conclusion it is obvious that there are substantially more failure possibilities for product operation errors by the end-customer compared to a production environment.

4.1. Failure Analysis

There are three main sources for information about product failures:

- Customer service reports provide information about failure modes that occur in the market and their likelihood.
- Failed products show traces of the failure mechanism. Profound analysis of failed products helps to clarify this mechanism.
- Social media in the internet to point out the weaknesses of a product and the service provided by the producer.

In the next step the cause and effect relationship shall be clarified. In classical product design two major tools are in use:

- The so-called system FMEA and the so-called design FMEA are used to point out weaknesses regarding the end-customer's usage of the product. The FMEA has turned out to be effective against the recurrence of previously known and analysed failures especially, if the counter-measures are applicable. It is unlikely that unknown failures are de-masked by an FMEA or that known but underrated failures would be counteracted in a sufficient manner. But the FMEA may be an important source to understand failures caused by operation errors.
- Failure tree analysis (FTA) demonstrates the cause chain in an exemplary manner. The cross-relations between the conditions for a failure are pointed out by the operators of the Boolean algebra which can provide an excellent understanding of the failure mode.

Both tools turned out to be an excellent vehicle to explore the mechanism of failure modes. Both methods exhibit one major disadvantage. They do not provide a solution to eliminate the failure mode. This is the situation when TRIZ and AFD become valuable assets.

4.2. TRIZ Conformal Failure Elimination

The consecutive question concentrates on the effective and efficient application of the TRIZ tools.

A presumably complete catalogue of potential failure modes is established in the first step. In this context known and hypothetical failure modes shall be taken into consideration. Especially failures caused by unintended operation errors, particular environmental conditions and their combination shall be taken into account.

The second step is the exploration of the cause and effect relationships for each failure mode. So far existing, the FMEA and the FTA may be useful assets. The cause and effect representation as described by Terninko et al. [2] turns out to be very effective because it supports the following steps. Again it is essential to encounter unintended operation errors, particular environmental conditions and their combination as a potential source for failures.

It is very important to verify the failure mechanism by the so called problem inversion, the intended reproduction of the failure by the support of resources provided by the system [9].

For the third step we have to distinguish the classical TRIZ and the modern TRIZ approach:

- In the classical TRIZ approach the existing cause and effect relationship shall be used to localise critical zones. For these critical zones physical and technical contradictions shall be formulated and substance field diagrams shall be set up.
- As previously mentioned the approach using the cause and effect representation as presented in [2] shows numerous advantages. The vital contradictions and the promising evolutionary challenges can be directly derived from the cause and effect representation. The risk of over-seeing possible solutions can be substantially reduced.
- The basic AFD approach is an advancement of modern TRIZ for problem solving. AFD focuses on the root cause chain that provides the failure. AFD request the failure reproduction (as a proof for failure understanding) and based thereon a failure model. For the sake of consistency it is requested that the elements of the failure model are available elements in the system or its environment.

In all cases TRIZ operators are identified that turned out to provide a problem solution in similar cases. The TRIZ operators can be inventive principles, standard solutions, combinations and special cases thereof.

In any case the solutions for any problem have to be integrated into a comprehensive concept that approximates the aim of a product which is insusceptible against unintended operation errors.

The fourth step is the validation of effectiveness under realistic conditions.

4.3. Examples for clever Elimination of unintended Failures by the End-Customer

There are numerous examples for Poka Yoke solutions against operation errors by the end-customer in the daily life:

- Fast fuses are used to protect the end-customer from hazardous voltage in the case sudden voltage drop. This can be understood as a separation in conditions. Current is quickly shut off in the case of a short circuit.
- A switchable element at (former) computer disks avoided unintended erasing of important data and enabled data management in the unprotected state. This

solution can be understood as separation in space for the reading head which is mechanically blocked in the protection mode and released in the delete mode.

- The front-window of a washing machine in operation is blocked against opening. This solution can be understood as a separation in time: window is closed while the machine is in operation and the window can be opened while the machine is in idle state.

5. Conclusion and Outlook

The elimination of unintended failures by the Poka Yoke is a state of the art approach in manufacturing. Mainly unintended failures by workers can be effectively avoided to occur.

The Poka Yoke approach and the avoidance of unintended failures by the end customer of a product show similar patterns, especially in their TRIZ conformal description.

A commonly applicable approach to counteract unintended failures by the end-customer has been developed and discussed. AFD provides an asset in the TRIZ conformal identification of the cause and effect chain which produces the failure. TRIZ itself enables the designer to derive solutions to eliminate, attenuate, circumvent or prevent any kind of failure, especially in the case of unintended operation errors.

References

[1] Genrich Altschuller – The Innovation Algorithm - Technical Innovation Centre – 2nd Edition 2005 Worchester MA – ISBN 0-9640740-4-4

[2] John Terninko, Alla Zusman, Boris Zlotin – Systematic Innovation – Introduction into TRIZ CRC Press 1998 – ISBN 1-57444-111-6

[3] Boris Zlotin and Alla Zusman – Directed Evolution – 2004 Ideation International – ISBN 9780981790725

[4] Robert B. Abernethy – The New Weibull Handbook – 5th Edition by Robert B. Abernethy Palm Beach 2007; ISBN 10-0-9653062-3-2

[5] Bernd Bertsche – Reliability in Automotive and Mechanical Engineering – 2008 Springer Verlag Berlin et al. ISBN 978-3-540-34282-3

[6] Geoff Tenant – Design for Six Sigma – Launching New Products and Services without Failure – 2003 Gower Publishing – ISBN 0-566-084341-1

[7] Jürgen Heß – A combination of TRIZ and Reliability Engineering to Develop Endurance Test Concepts – Journal of the European TRIZ Association ETRIA 2016 p45

[8] Victor Fey and Eugene Rivin – Innovation on Demand, Cambridge University Press 2nd. Ed. 2006 – ISBN 13-978-0-521-82620-4

[7] Shigeo Shingo - A Study of the Toyota Production Systems, Productivity Press Inc. 1st Ed. 1989, ISBN 0-915-29917-8

[8] Shigeo Shingo - Zero Quality Control: Source Inspection and the Poka Yoke System -Productivity Press Inc. 1st Ed. 1986, ISBN 0-915-29931-3

[9] S. Visnepolschi – How to deal with failures Failure prediction and Analysis using Anticipatory Failure Determination – Ideation International 2008 – ISBN 978-0-9817907-6-3

The Sustainable Approach to Corporate Real Estate Management in a Conceptual Circular Economy Model

Katarzyna Śmietana

University of Economics in Katowice, 1 Maja 50 Street , Katowice 40-287, Poland

Tel.: +48 695 30 90 09; fax: +48 32 2577510; *E-mail address:* katarzyna.smietana@ue.katowice.pl

Abstract

Modern *Corporate Real Estate Management (*CREM) should combine elements that in a sustainable manner take into account market demands, environmental concerns as well as the needs of users and the business environment. In addition, real estate management should result in achieving the highest efficiency and productivity. Balancing the economic, social and environmental objectives as a result of the implemented sustainability-oriented approach based on a conceptual circular economy model is an expression maturity of social responsibility in sustainable CREM processes. This paper aims to identify the determinants of sustainable corporate real estate management, taking into account sustainable development reporting guidelines by GRI G4. This paper is conceptual in nature and presents the assumptions of a holistic, system approach to corporate real estate management which the integration and formalization of knowledge about reporting. The author adopts the thesis that *Sustainable Corporate Real Estate Management* (SCREM) requires the improvement of existing real estate management processes and defining new ones, taking into account the sustainability benchmarking in a conceptual circular economy model. More efficient and effective corporate real estate management challenges modern real estate and infrastructure management.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: corporate real estate; circular economy; corporate real estate management.

1. Challenges and trends of modern real estate and infrastructure management

Real estate is one of the most important resources of an enterprise and its proper management is a condition for gaining competitive advantage. Modern *Corporate Real Estate Management (*CREM) should combine elements that in a sustainable manner take into account market demands, environmental concerns, as well as the needs of users and the business environment. In addition, real estate management should result in achieving the highest efficiency and productivity. Taking account of not only the economic but also the social aspects, including environmental ones, in striving to achieve the highest and best use that provides the property with its largest/optimized value, is a dilemma and challenge for investors, property and facility managers. Balancing the economic, social and environmental objectives as a result of the implemented sustainability-oriented approach based on a conceptual circular economy model is an expression maturity of social responsibility in sustainable CREM processes. The existing research on the concept of "sustainability" as a determinant of modern business management shows that what companies consider important is implementing the principles of corporate social responsibility, environmental management and social management into their management systems [13,17]. This approach is referred to as *corporate sustainability management* and may serve as a foundation for corporate real estate management [4, 16, 20, 22, 29, 33, 35, 36, 37]. The concept of *sustainability management* was incorporated into real estate management processes along with the development of the CREM theory, as a result of the changing role of CRE, new functions fulfilled

.

by this type of assets, challenges stemming from technological advances, new trends observed in the property market and the targets set for sustainable development, including environmental and social responsibility in connection with the observed climate changes and social expectations. An in-depth study of literature has helped to identify trends in the development of the CREM theory, whose main currents converge and are reflected in the concept of the circular economy, and determine the goals of strategic management.

Sustainable business model	Circular economy perspective Sustainability-oriented approach based on a conceptual circular economy model

1. The chronological development of the CREM theory - from administration through strategic management, to sustainable, integrated management of new business models [14, 15, 27, 34].
2. The development of the CREM theory in response to the need of focusing the management on individual assets and the real estate resource along with the infrastructure of an enterprise- building & property & facility management, real estate asset management, real estate portfolio management [1, 10, 21].
3. Management perspectives reflecting the changing functions of CRE - Business perspective, Financial perspective; Capital market perspective [23].
4. Management addressing the objectives of sustainable development - ESG perspective.
5. SCREM in Sustainable Business Model - Circular economy perspective.

A change has been observed in the perception of the role and objectives of the management of assets, including real estate regarded as one of the key business resources, alongside people and technology. What has been identified is a projected scenario of changes in the CREM system - the so called *transformational change*, which assumes the integrated management of resources of a modern organization connecting space (CRE), employees (HR) and technologies (ICTs), all of which co-participate in the realization of the mission of each entity [14]. The scenario has become a benchmark for the development of a conceptual SCREM model [37], based on the assumption of "the integrated resource management business model" that, in addition to resources, integrates concepts that are to ensure the sustainable management of these resources in the process of building long-lasting sustainability and balance of the company. In this model, the authors have identified the concept of CSR as having key importance in the organizations' endeavors to achieve sustainable development.

SCREM combines different concepts of strategic real estate management [37]. The systems approach is reflected in the concept of *facility management* (FM). FM is defined as the integration of processes in the management of real estate and infrastructure, aiming to provide the functionality of the construction environment by integrating people, places, processes and technology (IFMA, http://www.ifma.org/). The definition contained in the PN-EN 15221 [24, 26] emphasizes the importance of the integration of processes within the organization, aimed at the provision and development of agreed services which support and enhance the effectiveness of the core activities of the organization. The aim of FM system is therefore to create an urbanized environment in which the processes will be more efficient as a result of increased employee productivity. The standardized and integrated processes are to support and improve the effectiveness of the core business operations of an enterprise. Creating a sustainable construction environment in the CRE development and management processes is to be based on the assumptions of the concept of *sustainable development* (SD). Sustainable development is understood as meeting the needs of the society while taking into account the limitations of the natural environment of the planet and enabling the realization of the development aspirations of future generations. Social responsibility (SR), as a response to the challenges of SD, builds on this idea and remains closely associated with it. It refers to corporate social responsibility (CSR) in relations to the stakeholders, including the public and the environment, and the realization of specified targets is to add to maximizing the contribution of the organization to sustainable development. The concept of social responsibility, considered in accordance with the guidelines of ISO 26000 EN/ISO 26000:2012 [25], in the context of the functioning of a socially responsible enterprise assumes its willingness to take into account social and environmental issues when making decisions and activities, and to disclose the impact of those decisions and activities on the society and the environment. This is an attitude that represents ethical and transparent actions of enterprises, contributing to sustainable development in accordance with applicable law and consistent with the accepted standards of conduct. In real estate management, this will be understood as management according to specified objectives of environmental sustainability, social responsibility and environmental, social and corporate governance (ESG). At the same time, there is emphasis on the particular importance of using ICT in the system of sustainable corporate real estate management. In this system, ICTs are a factor stimulates the activity in the following areas: the environment, creating a sustainable work environment and the corporate board.

2. The assumptions of "circular economy" and the objectives of sustainable corporate asset management

The Sustainable Approach to Corporate Real Estate Management in a Conceptual Circular Economy Model expresses a proposal of an established procedure allows defining the determinants and identifying guidelines for reporting by GRI G4 [7, 8], useful for companies wishing to implement good practices of the circular economy. The presented concept enables the determination of targeted measures to optimize the processes of sustainable resource management, contributing to the achievement of a higher level of maturity of corporate social responsibility for the environment, and thus achieving sustainable development objectives. The concept involves taking the following into account: the context of sustainable development, corporate social responsibility (CSR), the circular economy models and guidelines for integrated reporting of environmental aspects. The context of sustainable development is based on four pillars that are relevant to the analysis of the environmental responsibility of an enterprise: "nature conservation",

"reduced toxicity", "resource efficiency", "social ecology", "cultural ecology" (28). Referring to the concept of social responsibility analyzed in the five dimensions of responsibility: economic, environmental, ethical, social and organizational, it was assumed that the effectiveness of the organization in every dimension determines the integrated efficiency of the unit, whose activities are to support sustainable development, with environmental responsibility being of key importance in achieving the circular economy goals [2, 19, 28]. The orientation of an enterprise on CSR and sustainable development objectives involves a conscious approach and appropriate preparation, ensuring the collection and preservation of information, processes approach targeted at internal and external stakeholders under certain conditions of work environment, as well as people & place, and a sustainable product & production. Corporate Real Estate Management in a Conceptual Circular Economy Model should be supported by new ideas, which will be reflected through good management practices [9,18,19], including 1. Measures for achieving the objectives of low-carbon business, including improving processes to increase energy efficiency/productivity and carbon management aimed at the ultimate reduction of the carbon footprint of a target to achieve and maintain the state of zero emissions. 2. Green IT. 3. New business models derived from the concept of circular economy as determinants of sustainable resource management in the organization. In summary, a strategy assuming a sustainability-oriented approach based on a conceptual circular economy model will become a challenge for the modern enterprise asset management. The concept of the circular economy assumes the use of new business models (Table 1), the application of which would contribute to reducing the unfavorable environmental impact of business activities, including those used in these real estate processes and infrastructure. The implementation of the circular economy will determine the highest maturity level of the organization's responsibility for the environment.

Table 1. Circular economy models - CSR orientations versus CIRCULAR ECONOMY

CSR ORIENTATIONS	CIRCULAR ECONOMY
PROFITABILITY ORIENTATION COMPANY – Brand; Value	"The circular supply-chain" "The recovery & recycling" "Product life-extension"
TRUSTEESHIP ORIENTATION	"Sharing platform"
QUALITY OF LIFE	"Product as a service"

"Circular economy is a system of exchange and production which, at every stage of the product lifecycle (goods and services), is aimed at increasing the efficiency of use of resources and reducing the impact of production activities and consumption on the environment" [9]. There are six main elements constituting the foundation of that conception [9]: "moderate and as efficient as possible use of non-renewable resources; renewable resource exploitation that is respectful of the conditions of renewal of these resources; eco-design and clean production; eco-friendly consumption; recycling of waste as resources; non-polluting waste treatment. Scientific origins of circular economy with ecological approach are presented by E. MacArthur Foundation" [9, 12]: Regenerative Design; Performance Economy; Cradle to Cradle; Industrial Ecology – Strategy for Manufacturing; Biomimicry; Blue Economy with analysis of factors favorable to a transition to that conception. These include the increasing scarcity of resources, restrictive environmental norms, and high-performance well-suited technologies to the implementation.

The concept of a circular economy assumes the imperative of using natural resources in the most sustainable and intelligent way. In the business model, it is understood as a philosophy of promoting and implementing measures for more efficient and productive use of resources in the pursuit of creating sustainable value in every link of the system, including the green supply chain that is of key value. The "green supply chain" is one of five new business models, which in principle have been designed to promote sustainable growth. "The Circular Supply-Chain" involves the use of a fully renewable, recycled and biodegradable materials which can be applied in subsequent cycles of life and hence contribute to the reduction of cost and risk related to their use. "The Recovery & Recycling" model creates systems of production and consumption, with the assumption of the possibility of re-using all components, valuable materials and energy from renewable sources. "Product Life-extension" implies taking action to reduce or eliminate economic consumption of products through their proper management, including improvements aimed to maximize the usage period. The "Sharing Platform" model, by providing efficient management of dispensable corporate assets, and the "Product as a Service" model, determining an opportunity to build long-term relationships with enterprise customers, provide after-sales services as a result [18]. It is recognized that the concept was created by W.R. Stahel, who in 1976 prepared a report for the European Community, which contained the idea of the circular economy whose assumptions were specified in his later scientific papers [32]. The concept involves adopting business solutions, including the use of human resources and product changes that affect the reduction of the utilization of resources, including energy. The development of the concept resulted in the specification of its determinants [32]: the need to eliminate waste, using renewable energy, managing water use, promoting diversity and healthy ecosystems, respecting the interests of local communities, applying social responsibility in the activities and relationships with stakeholders. The circular economy is therefore both a philosophy, as well as a specified action plan which fits into a specific business model, diversified due to the nature of an enterprise - industry affiliation of the organization, in each case allowing to specify targets expressed in the economic, environmental and social dimension and thus, to create sustainable value, stimulating growth without harming the environment, including the natural environment and valuable ecosystems. In the business environment, the concept of "circular economy" is considered as an idea, which is a leverage spurring innovation in products, services, technologies, systems and processes. There is emphasis on the need for proper organization, integration and optimization of processes using information and communication technologies to reduce the negative environmental impact of enterprises and the infrastructure used by them. Three fundamental

drivers of the development of the circular economy are: limited resources, technological development and socio-economic challenges. It is pointed out that the modern economy does not guarantee the sustainable management of resources, therefore one seeks mechanisms and new models which are becoming a response to new challenges. Modern technologies, in particular innovations related to information and communication technologies, are an attractive instrument of the circular economy, the use of which is not so much justified as necessary, both from the scientific and economic point of view. A challenge for the circular economy is the intelligent use of assets. Extending the life cycle of products, while helping to reduce operational costs. This is the purpose of the optimization of systems essential for achieving the objectives of sustainable development of enterprises [18, 11]. Applying the circular economy to the built environment (construction sector, buildings) is expressed through design principles and sustainable corporate real estate management practices. Designing (sustainable) buildings and ecosystem by selecting materials and products that ensure their flexibility, adaptability, "designing-out waste" and "design for disassembly" should allow them to retain their value by avoiding economic, technical, technological, functional and environmental obsolescence. In the construction sector it means e.g. Cradle to Cradle Certified products characterised by the following categories: material health, material reutilization, renewable energy and carbon management (International Energy Agency's Photovoltaic Power Systems Program), water stewardship – Integrated Water System, capture, recycle and reuse; Integrated Stormwater Management; Water Efficiency; social fairness [6, 3]. A circular built environment could be created by sustainable CREM processes, such as: Sharing platform – shared spaces and renting; Cradle to Cradle innovation platform for improving quality and good business – Carbon reduction strategy with effectiveness results in a significant, beneficial footprint [12]; Product as a service – IT Infrastructure, Data Management and analytics (Green IT – Data & Analitycs & Environmental Benchmarking); Maintenance as a service [30]; Lighting as a service (Philips "Pay-per-lux" model – lighting maintenance, lighting performance and periodic online reporting of energy use, health checks and preventive maintenance [6]. Circular economy concepts should be applied to the materials, methods used in buildings and infrastructure in constructing and space planning. Economic durability and economic value, sustanable real estate value proposition and corporate values, could express qualitative effects of a circular economy transition – direct, indirect and induced effects be made through the implementation of innovation, including eco-innovations. Eco-innovations will support the objectives set for the low-carbon business and low-carbon economy.

3. **The implementation of the circular economy in SCREM - reporting of environmental aspects by GRI G4**

The analyzed goals of sustainable corporate real estate management clearly point to the validity of integrating corporate social responsibility and other norms and standards with the activities of organizations in terms of the management of real estate and infrastructure in their business operations. This assumption is confirmed by sustainable development strategies formulated by CoreNet Global, which indicate the importance of both formal and non-formal documents allowing targeted actions for the sustainable development of the organization [5]. They comprise: standardization, including the implementation of ISO standards; development of the established formal policies, including environmental management; disclosure of target indicators showing the potential for reducing the negative impact of business activities on the environment; planning activities across the organization for the implementation of good practices in support of sustainable development. The implementation of objectives in this area will be supported by management systems with specified ESG (Environmental, Social and Governance) goals, either developed independently or offered to enterprises. Reporting (ESG reporting) "is a generic term used in capital markets and by investors to evaluate corporate behavior and to determine the future financial performance of companies. ESG factors are a subset of non-financial performance indicators which include sustainable, ethical and corporate governance issues such as managing the company's carbon footprint and ensuring there are systems in place to promote accountability" [31]. Among the recommended standards, which could support the sustainable management of corporate real estate and infrastructure, there are guidelines for quality management, property management, benchmarking, as well as corporate social responsibility and stakeholder engagement. Implemented to SCREM, they will contribute to the sustainable management of real estate, creating a system to support the sustainable development objectives within the assumptions of the circular economy. A conceptual model of circular economy is an expression of the maturity of social responsibility in sustainable CREM processes. The level of the orientation of a business on CSR as a determinant of the maturity of corporate social responsibility will be determined by actions having the characteristics of good practices. They shall be documented, their results shall be reported and benchmarking will be conducted based on the existing CSR policies (ESG guidelines or other). The benchmarking should allow for a comprehensive assessment of CRE against market standards, which serves as the basis for making the right decisions about the future in terms of improving the productivity of real estate and infrastructure. In practice, benchmarks are worked out independently by enterprises, acquired on the basis of the mutual sharing of data within organizations, industry associations and purchased in the form of reports or reference measures. KPIs-Key Performance Indicators (Control Indicators) are a business metric used to evaluate factors that crucial to the success of an organization. KPIs differ per organization/entity based on its purpose, business model and drivers for value creation. EU Accounting Directive includes description of the undertaking's business model and non-financial key performance indicators relevant to the particular business and UE initiatives enhancing corporate reporting. "Global Reporting Initiative (GRI) is a leading organization in the sustainability field. GRI promotes the use of sustainability reporting as a way for organizations to become more sustainable and contribute to sustainable development. "Is gaining more ground in the area of non-financial information and is driving sustainability reporting by increasing number of organizations. Its comprehensive Sustainability Reporting Framework is widely used around

the world to enable greater organizational transparency. In 2013 GRI issued the G4 Sustainability Reporting Guidelines issued a paper analyzing the interaction between the GRI G4 guidelines and the EU Accounting Directive" (FEE Federation of European Accountants, 2015).

Referring to the adopted purpose of the work and the assumption stating that: *Sustainable Corporate Real Estate Management* (SCREM) requires the improvement of existing real estate management processes and defining new ones, taking into account the sustainability benchmarking in a conceptual circular economy model, the author proposes linking the pillars defining sustainable development in the environmental context with the assumptions of the Circular Economy and reporting of environmental aspects in accordance with the GRI guidelines G4 (Fig. 1).

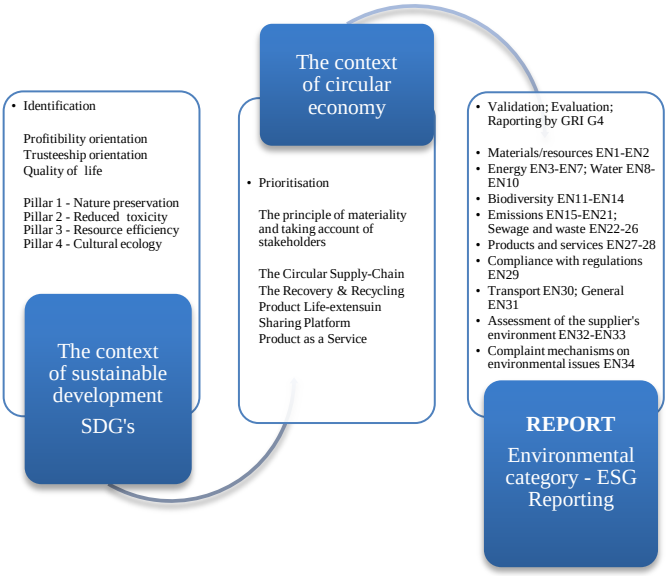


Fig. 1. Sustainability benchmarking based on GRI G4 in a conceptual circular economy model.

The environmental dimension of sustainable development that is relevant to the objectives of the circular economy refers to the impact of the organization on animate and inanimate natural systems, including soil, water, air and ecosystems. The environmental category contained within GRI G4 [7, 8] includes impacts associated with the initial products (such as energy and water), the starting products (such as emissions, sewage and waste), biodiversity, transportation and impacts related to products and services, as well as compliance with environmental regulations.

Results

The analysis of the GRI guidelines and of the four-stage process of defining the contents of the report presented above, allows one to determine the usefulness of this procedure for enterprises whose goal is to identify actions which constitute good practices in the implementation of the circular economy principles. The stages of the process, including: identification (stage I), prioritization (stage II), validation (stage III), and evaluation and reporting (stage IV), will make it possible to define targeted measures to optimize SCREM processes in the dimensions of the sustainable management of resources, thus contributing to the achievement of higher maturity of social responsibility of the organization for the environment, thereby meeting the objectives of sustainable development. It should be emphasized that the proposed procedure can be a useful tool for companies which form the pillars of a sustainable business model, implementing the CSR strategy, as well as for the organizations that do not plan such activities. It will be useful in particular for entities obliged to integrated reporting in accordance with the EU Directive - Directive of the European Parliament and of the Council 2014/95/EC of 22 October 2014 on the reporting of non-financial data, including data on the environment, society and employment, and integrating it with financial reporting. Directive establishes that the non-financial statement shall include a description of the undertaking's business model, the principal risks and non-financial key performance indicators relevant to the particular business. Companys could applied circulare econymy such as business model to achieve more efficient and effective corporate real estate management system challenges modern real estate and infrastructure management.

References

[1] Ali Z., McGreal S., Adair A., Webb J.R. 2008, *Corporate real estate strategy: a conceptual overview*, "Journal of Real Estate Literature", 16(1), pp. 3-21.
[2] Brockett A.M., Rezaee Z. 2012, *Corporate sustainability. Integrating performance and reporting*, John Wiley & Sons, Kindle Edition.
[3] *Circular business opportunities for the built environment, A new dynamic 2, Effective systems in a circular economy* (2016). Edited by the Ellen MacArthur Foundation, Ellen MacArthur Foundation Publishing, United Kingdom, pp. 9-29.
[4] CoreNet global (2012). *The Corporate Real Estate 2020, Sustainability Report*, www.corenetglobal.org.
[5] CoreNet Global (2015). *The essential guide to corporate real estate*, Kindle Edition.
[6] Cheshire D. 2016, *Building revolution. Applying the circular economy to the built environment*, RIBA Publishing, pp. 95-96, pp. 110-111.
[7] G4 *Wytyczne dotyczące raportowania. Podręcznik stosowania wytycznych* (Guidelines for reporting. Manual for the application of the guidelines), GRI 2016, www.globalreporting.org.
[8] G4 *Wytyczne dotyczące raportowania. Zasady raportowania i wskaźniki* (Guidelines for reporting. The principles of reporting and indicators), GRI 2016, www.globalreporting.org.
[9] Gallaud, Laperche. 2016, *Circular economy, Industrial Ecology and Short Supply Chain*, John Wiley & Sons, Kindle Edition.
[10] Glatte T. (2012). *The importance of corporate real estate management in overall corporate strategies*. CoreNet Global.
[11] *Gospodarka o obiegu zamkniętym, Jak wyzwolić potencjał z planowanych zmian* (2016). Deloitte Sustainability Consulting Central Europe, Warszawa.
[12] *Growth within: a Circular Economy Vision for a Competitive Europe* (2015). Ellen Macarthur Foundation. https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe.
[13] Grudzewski W.M., Hejduk I.K., Sankowska A., Wańtuchowicz M., 2013, *Sustainability w biznesie czyli przedsiębiorstwo przyszłości. Zmiany paradygmatów i koncepcji zarządzania/ Sustainability in business - the business of the future. Changes in paradigms and management concepts*, Poltext, Warszawa.
[14] Harris R., Cooke H. 2014, *Is corporate real estate at a crossroads?* "Journal of Corporate Real Estate", 16/4, pp. 275-289.
[15] Haynes B., Nunnington N. 2010, *Corporate real estate asset management: strategy and implementation*, Taylor & Francis. Oxford, Kindle Edition.
[16] Haynes B.P., 2012, *Corporate real estate asset management: aligned vision*, "Journal of Corporate Real Estate", Vol. 14 No. 4, 2012, pp. 244-254, http://dx.doi.org/10.1108/JCRE-10-2012-0022.
[17] Hejduk I.K., Grudzewski W.M, 2014, *Koncepcja sustainablity wyzwaniem współczesnego zarządzania/ The concept of sustainability as a challenge of modern management*, w: *Koncepcja sustainability wyzwaniem współczesnego zarządzania/ The concept of sustainability as a challenge of*

modern management, red. nauk./ed. I. K. Hejduk, Oficyna Wydawnicza SGH, Warszawa 2014, pp. 11-28.
[18] Lacy P., Rutqvist J. 2015, *Waste to Wealth, The Circular Economy Advantage*, Kindle Edition, Palgrave Macmillan.
[19] Lucas, M.T. 2009, *Understanding environmental management practices: integrating views from strategic management and ecological economics*, "Business Strategy and the Environment", 19(8), pp. 543-556.
[20] Laposa S.P., Villupuram S. 2010, *Corporate real estate and corporate sustainability reporting: an examination and critique of current standards*, "Journal of Sustainable Real Estate", 2(1), pp. 23-49.
[21] Lindholm, A.L. 2008, *A constructive study on creating core business relevant CREM strategy and performance measures*, "Facilities", 26(7/8), pp. 343-358.
[22] Masalskyte R., Andelin M., Sarasoja A.L., Ventovuori T. 2014, *Modelling sustainability maturity in corporate real estate management*, "Journal of Corporate Real Estate", 16(2), pp. 126-139.
[23] Nappi-Choutet, Liow, 2008, *A combined perspective of corporate real estate*, "Journal of Corporate Real Estate", Vol 10 No. 1, 2008, pp. 54-67.
[24] PKN (2012) EN/PN 15221-1:2012 *Facility Management. Część 1: Terminy i definicje/ Facility Manaement. Part 1: Terms and definitions*, Polski Komitet Normalizacyjny, http://www.pkn.pl/, licencja PKN dla UE w Katowicach, z dn. 22.03.2013./the Polish Committee for Standardization, , http://www.pkn.pl/, a PKN licence for EU in Katowice of 22 March 2013.
[25] PKN (2012). EN/PN-ISO 26000:2012 *Wytyczne dotyczące społecznej odpowiedzialności (Guidelines on social responsibility)*, http://www.pkn.pl/, licencja PKN dla UE w Katowicach, z dn. 09.01.2014./ a PKN licence for EU in Katowice of 09 January 2014.
[26] PKN (2013) EN/PN 15221-5:2013 *Facility Management – część 7: Wytyczne dla benchmarkingu/Facility management – part 7. Guidelines for benchmarking*, Polski Komitet Normalizacyjny, http://www.pkn.pl/, licencja PKN dla UE w Katowicach, z dn. 09.01.2014./ a PKN licence for EU in Katowice of 09 January 2014.
[27] Roulac S. 2001, *Corporate property strategy is integral part to corporate business strategy*, "Journal of Real Estate Research", 22 (1/2), pp. 129-152.
[28] Scott J.T. 2013, *The Sustainable Business*, A Practitioner's Guide to Achieving Long-Term Profitability and Competitiveness, Taking the First Steps Toward Understanding, Implementing and Managing Sustainability from a Cost/Profit Perspective, the European Foundation for Management Development, Greenleaf Publishing Limited, www.greenleaf-publishing.com.
[29] Stibbe R., Voigtländer M., 2014, *Corporate sustainability in the German real estate sector*, Journal of Corporate Real Estate , Vol. 16, Iss 4, pp. 239-251, http://dx.doi.org/10.1108/JCRE-10-2013-0030.
[30] *Strategic facilities management* (2013). RICS guidance note, global, rics.org/guidance.
[31] *The Future of Corporate Reporting – creating the dynamics for change*. FEE Federation of European Accountants October 2015 www.fee.be.
[32] Tundys B. 2015, *Zielony łańcuch dostaw w gospodarce o okrężnym obiegu – założenia, relacje, implikacje*, (*Green supply chain in circular economy − assumptions, relations, implications*), Redaktorzy naukowi/Ed. J. Witkowski A. Skowrońska, Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu, nr 383, pp. 288-301. DOI: 10.15611/pn.2015.383.21
[33] UNEP_FI (2014). *Sustainability metrics, Translation and impact on property investment and management*, Lützkendorf T., Lorenz D., www.unepfi.org.
[34] Varcoe B., O'Mara M. (2011). *Corporate real estate impact on enterprise success*. Regus Global Report.
[35] Wilkinson S.J., Pinder J., Franks, A., 2004, *Conceptual understanding of corporate social responsibility in the UK construction and property sectors*, Building for the Future: The 16th CIB World Building Congress 2004, Rotterdam (Netherlands)**;** http://www.irbnet.de/daten/iconda/CIB1764.pdf
[36] Wilkinson S.J., Sayce S.L., Christensen P.H. 2015, *Developing property sustainably*, Routledge Taylor & Francis Group.
[37] Ziemba E., Śmietana K., Ramian T., Kania K. 2016, *The Concept Of A Sustainable Approach To Corporate Real Estate Management*, Real Estate Management and Valuation. Volume 23, Issue 4, pp. 85-94.

Towards an expansion of TRIZ methods into the strategy creation space

Michael Ohler[1*], Philip Samuel[2], Naresh Shahani[3] and Derek Bennington[4]

[1]*Innovation Practice Leader, BMGI, Buchsbaumweg 6, 22880 Wedel, Germany*
[2]*Chief Innovation Officer, BMGI, 1200 17th Street, Suite 180, Denver, CO 80202 USA*
[3]*General Manager, BMGI India, 905/906 Raheja Chambers, Nariman Point, Mumbai 400021, India*
[4]*Managing Director, The TRIZ Journal, 1200 17th Street, Suite 180, Denver, CO 80202 USA*

* Corresponding author. Tel.: +49 151 28415103. *E-mail address:* Michael.Ohler@bmgi.com

Abstract

TRIZ practitioners can rightly claim they master a robust and comprehensive set of approaches for tackling a broad range of business challenges. Organizations need to identify the right things to do (strategy creation) and then plan (strategic planning) and do them the right way (strategy execution). Known for their predictable results, TRIZ experts are brought in for doing things the right way. This article looks at the support provided for finding the right things to do within an organization and what contribution TRIZ can make in the domain of strategy creation.

Using a framework for operational strategy allows discussing the integration of approaches associated with strategy creation and TRIZ methodologies in order to enhance strategy processes within an organization. We find that TRIZ can help organizations in sharpening and operationalizing the creation of strategy.

ISSN 1866-4180 © 2017 The Authors. Published by ETRIA.
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Strategy; Strategic Thinking; Strategy Creation; Strategic Planning; Divergent and Convergent Thinking; Trends; TRIZ Integration; Opportunity Exploration

1. Formal strategic thinking – a short overview for TRIZ practitioners

With over 600 million hits in a Google query, 230,000 results for an Amazon book search and over 10 percent of the main author's LinkedIn connections having "strategy" or "strategic" in their title, "strategy" certainly has turned into one of the most used terms in today's business.

It should therefore first be noticed that the application of strategies is not limited to business and not even to the human world. Wolves, cheetahs, crocodiles, spiders, orcas and many other animals have developed elaborate and distinct ways for going after their prey by using teamwork, resources such as hides, core strengths like peak speed or endurance, and unique assets such as an ability to produce long anchor lines for a spider web. These animals bring to best use their intelligence and choose from an often surprising variety of tactics.

"Stratos agein" derives from Greek for "leading the troops". Across cultures, we dispose of 2,500-year old accounts on strategy: Sun Tzu from China and *The Art of War* [1]; in Ancient Greece Thucydides and *History of the Peloponnesian War* [2], as well as speeches by Pericles and other leaders; and in India *Mahabharata* [3] have all been written at about the same time. These traditions differ in emphasis: while Sun Tzu derives formal rules for the strategist to use, Thucydides appears more interested in the underlying drivers in human nature, Pericles in the leveraging of political and economic forces for the creation of strategy, and the *Mahabharata* in sharing inspirational and instructional cases. Much has been added since, by Machiavelli, Clausewitz and Mao and many others. All this body of knowledge is studied by and has shaped

the thinking of military and other strategists and has contributed to strategic thinking being practiced differently in different cultures. While Phoenician merchants, the Medici and other historic "business people" all have developed and used successful strategies, over thousands of years the scripting of strategic thinking seems to have mainly been reserved for the military and political domains and its emergence in business appears a modern phenomenon as seen in a recent overview published by Lawrence Freedman in *Strategy: A History* [4].

Faced with this diversity, the TRIZ practitioner may ask if there were a limited set of possible strategies. Knowing Sun Tzu did not declare his account "complete", TRIZ author Kai Yang set out to compare the 36 strategies in "The Art of War" to Altshuller's 40 inventive principles. His investigation [5] shows an important overlap between the two: strategy and TRIZ re-use existing knowledge in order to overcome psychological inertia and to create unusual solutions for difficult problems. Hence, TRIZ methods can be seen as a method for the practice of strategy. However, each of the two domains can also claim ground for itself and it is important to understand more closely which aspects of strategy can best be addressed with TRIZ methods.

A TRIZ practitioner knows there are 40 inventive principles, so it's obvious to ask: Is there also a limited set of possible strategies? The answer appears still unclear. L. Freedman groups the panoply of approaches into military "strategies by force", political "strategies from the bottom" and business-like "strategies from the top". Such a classification helps the practitioner not fall prey to mental inertia. For example, a military strategist can indeed apply bottom-up strategies (e.g., General Stanley McChrystal, *Team of Teams* [6]).

Cultural preferences in the practice of strategy can also be seen in games and sports. Sports often use "strategies by force". Years of experience in following baseball, football or soccer, for example, provide the strategy practitioner with a pool of analogies that will shape his or her thinking. Furthermore, since its early days, strategy is not only formalized in writing and language but also in strategy games, such as Go or Chess, and the practice of these games shapes strategic thinking (see *Learning from the Stones* [7] and "Chess, what is it good for?" [8]). While these two games and many others, including a range of modern computer-aided games, can be seen as being based on "strategy by force", a growing number of strategy games, electronic or not, also foster "bottom-up" and "strategy from the top" thinking or build more on cooperation and collaboration than on competition. The practice of strategy does not necessarily require an "enemy" or competitor. Indeed, the creation of a purposeful strategic approach seems useful whenever "agents" equipped with intelligence and free will are relevant in a resource-constraint setup.

The TRIZ practitioner's next question is whether an "algorithm" or at least a roadmap for strategy creation can be found. The simplest possible and often discussed two-phased roadmap is the distinction between "strategy" on the one hand and "execution" on the other. That debate may well have been concluded by Roger L. Martin: "Stop Distinguishing Between Execution and Strategy" [9] – because the two belong together. A strategy that can't be executed is not a "good strategy" (see Richard Rumelt's *Good Strategy Bad Strategy* [10]): Leaders remain accountable after the creation of strategy for its execution.

Inspired by the availability of problem solving roadmaps in other areas, such as TRIZ, DMAIC, 8D, PDCA or others, over the past years, we have developed and used with a number of clients from different industries the five-phased strategy roadmap shown in Figure 1. In this view, the execution of strategy is seen as implementation and transformation followed by anchoring the results in a new daily routine. Before executing a strategy, it needs to be carefully planned. Strategy practitioners also take great care to not confuse planning with the very creation of strategy. Divergent strategic thinking, recognized as a phase of its own, provides inputs for the more convergent building of strategy, which then feeds into planning.

Several well-rounded methodologies exist for strategic planning (e.g., Hoshin Kanri [11] and the Balanced Scorecard), as well as for execution through improvement projects using Lean, Six Sigma, Kaizen and 8D, and innovation projects using TRIZ, Design Thinking and Outcome-Driven Innovation [12]). There is also much written on excellence in daily management. It seems to the authors that the pursuit of systematic methods for strategy creation, the front end of the model shown in Figure 1, is an interesting endeavor, especially for practitioners of systematic innovation methods like TRIZ.

We thus propose using the clarity and structure of TRIZ thinking in order to critically look not at different "strategies" but rather at approaches of how these are created in the first place. The idea is to build on Kai Yang's earlier work by studying strategy creation tools and approaches and to contrast them with TRIZ methods, and vice versa. This will also allow for the discussion of how TRIZ practitioners can contribute to strategy creation. The present article is a first step into this direction.

Figure 1: Roadmap for creation, planning and execution of strategy.

2. Strategy creation requires taking a diversity of views

With millennia of strategy as a practice and a growing wealth of business literature on the topic, one may be surprised to find only a good handful of strategy tools regularly applied in many organizations. Among these are Porter's Five Forces (competition, new entrants, customers, suppliers and substitute

offerings) [13], the SWOT analysis (strengths, weaknesses, opportunities, threats), the Growth-Share Matrix [14], Business Model Innovation [15, 16] and the formulation of a vision of the future.

One way of structuring these and other strategy creation tools and approaches is to map them into a strategy roadmap, such as the one shown in Figure 1: Is any given tool more suited for strategic thinking, for building strategy, for planning it? Here we focus on acknowledging that strategy creation requires taking a variety of perspectives. One can look at how much any given method fosters an "analytical" versus an "intuitive" or an "outside-in" versus an "inside-out" view, or whether it supports better divergent or convergent thinking, how much it relates to people's different problem solving styles ("Classification of TRIZ Techniques Using a Cognition-Based Design Framework" [17]) or how it can be used when working in problem solving teams as opposed to boosting the creativity of the individual practitioner.

For example, Porter's Five Forces offer a structured "outside-in" and analytical view. When studying the corporation's "core competence" [18], the view is equally analytical but with a stronger "inside-out" emphasis. Interestingly, data-analytical methods (see for example *Competing on Analytics* [19]) can be applied with a view on the outside market and also by looking at the production and supply chains, which is the essence of "Industry 4.0" [20].

It has also been seen over and over again that creating strategy isn't an area only of left-brain analytical thinking, but also of right-brain intuitive thinking. Among the suitable, more intuitive approaches to support the strategy practitioner are "design thinking" [21], with an emphasis on the "outside-in" view and a strong focus on developing empathy. On the other hand, "LEGO SERIOUS PLAY" [22] offers interesting ways to foster an inside-out view: in order to know who you can become (vision) you have to know who you are (current reality). Notice that both these methods use "gamification" [23] in order to unlock the otherwise tacit or hidden potential in creative teams.

Furthermore, when seen as "management philosophy", Lean, Six Sigma, Quality Function Deployment, as well as Blue Ocean Strategy [24] and innovation methods around the concepts of the Job-To-Be-Done [25] and outcome expectations have been explicitly developed for or successfully applied to the creation of strategy, and the intention here can't be to provide an exhaustive list. One also needs to acknowledge that some practitioners of the cited practices may consider their art as "holistic" in the sense that they might not necessarily see the need for other methods. In that view, the intention of Figure 2 is to provide the non-practitioner of strategy with an overview rather than to pigeonhole any respectable school of thought in a given corner of an x-y diagram.

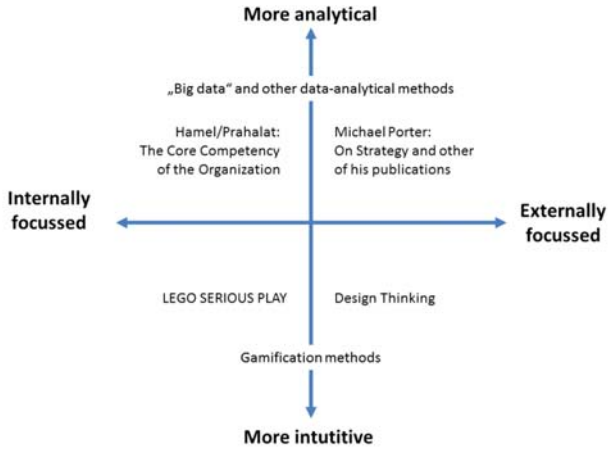


Figure 2: Selected approaches for creating strategy and their focus.

In order to study how TRIZ methods relate to approaches for the creation of strategy, we propose to contrast them with their perceived closest equivalents in strategy creation. This appears a larger undertaking, and here we look at Ideal Final Result. The same can also be done for Ideality, Function Analysis, Resource Optimization, Nine Screens, Contradictions, Effects, Su-field modeling, Trend Analysis, and for the "Small Little People" method – to name some of the most commonly used TRIZ approaches.

At the same time, one can also look at strategy tools and methods and map them to TRIZ methods. Thankfully, prior work is available. For example, Claudia Hentschel looks at Design Thinking as a door-opener for TRIZ [26]. Her work could, and we believe should, be continued and expanded to more approaches shown in Figure 2, as well as to the wealth of other methods for strategy creation in order to help the strategy practitioner source from the art and craft of TRIZ and the TRIZ practitioner contribute to the creation of strategy.

3. On the use of the Ideal Final Result in strategy creation

An obvious equivalent in the strategy creation space of the Ideal Final Result in TRIZ is the formulation of a vision for the future. For TRIZ practitioners the Ideal Final Result (IFR) has a specific operational meaning: It is the solution that causes no harm while providing all the benefits, it has no weight, requires no effort and so forth. In problem solving, the formulation of the IFR helps individuals and teams to break free from mental inertia, preconceived ideas and imagined or real barriers to create previously un-thought-of and surprising solutions.

For example, if the problem were to find an ideal way to "paint my garden fence", one can describe the IFR in the following three ways: A) Remove the need to solve this problem by solving it on a higher level: "What is the purpose of a painted fence and can I address that purpose directly and without needing to paint it or even without having a fence in the first place?" B) Find a self-solution: "Can't the fence paint or at least re-paint itself?" C) Find a free resource that can do the job on our behalf: "Isn't there a field, a physical, human or

any other visible, invisible, useful or even harmful resource within or outside the system that we can use or which wouldn't care or even love painting the fence on our behalf?" As we know, it is the last formulation that Mark Twain's Tom Sawyer had in mind when he was castigated to paint Aunt Polly's fence [27].

Please notice that in this context some practitioners employ the concept of the Job-To-Be-Done [28] to formulate in a solution-neutral way first the job someone is trying to get done and then what matters while getting it done, the outcome expectations. That is useful because for some people "painting" might imply the use of a brush. In that case, the very term could drive undesired mental inertia. Furthermore, studying a job executioner such as Tom, e.g., by using ethnographic methods (their application in business is also known as "empathetic" [29] or "contextual design" [30]), one can extract outcome expectations, such as maximizing Tom's social recognition and minimizing his personal effort for getting the job done. Hence, the three ways to formulate the IFR, eventually together with a clear definition of the Job-To-Be-Done and of the outcome expectations as identified through ethnographic methods, allows developing options for an ideal solution and also a clear and, through the concept of the "opportunity algorithm" [31], even a quantifiable understanding of what benefits, cost and harm are in the eyes of the job executioner.

Different from the clear definition of the IFR in the practice of TRIZ, the concept of a "vision" finds a range of meanings in strategy work. For example, a "vision" can be the description of a specific mid- or long-term future-state that the organization aims to reach at a given moment in the future. It can also be an ever-unreachable ambition. While the latter may be seen as coming closer to the IFR and as being well-suited for divergent thinking, it tends to be the former that is used as the first step in the Hoshin Kanri approach to strategic planning in order to help converge towards specific strategic choices.

For example, a car manufacturer might aspire to become the "leading mobility provider in the 21st century". Yet, what if that meant "parts assembled in Detroit, Wolfsburg or Esztergom, powered by Apple and delivered to you by Uber"? In order to drive specific choices and the selection of specific actions, this vision must be made more specific. For that, it must be based on robust strategic thinking and good research and be linked to "bets" on how the future might evolve. When multiple outcomes appear possible, then strategy practitioners may prefer planning for specific scenarios [32] instead of using a generic catch-all, lowest-denominator vision.

With their understanding of and practical experience with the IFR, TRIZ practitioners can certainly help strategy teams with the application of rigorous and systematic ways to create a vision out of manifold and detailed results coming from strategic thinking. In our experience, that support should be provided carefully and in a humble manner because, as has been seen through the quoted work, a lot of "prior art" exists in the field of strategy creation in general and also specifically around the formulation of a vision (see Joel Barker and "The Power of Vision" [33]).

Furthermore, a practitioner used to solving specific and often technical problems is likely to encounter situations in which the concept of the IFR can't readily be applied when figuring out, for example, how to position an automobile manufacturer in a business-world based on a "sharing economy" and shaped in many aspects by several deep-pocketed and dynamic information-technology companies.

Many TRIZ practitioners may also consider the formulation of the IFR as part of the definition phase, which goes in line with the practice of the Hoshin Kanri approach to strategic planning. Yet, considering the formulation of a vision as part of the building of strategy (see Figure 1) implies it must flow from prior strategic thinking. Hence, formulating a vision (or "visions" for different scenarios) is seen rather as a "summary tool" and not so much a "definition tool": it can't be created out of thin air.

For example, for the mobility industry, robust strategic thinking would be needed to answer whether a "sharing economy" [34] or a "circular economy" [35] would be the stronger driver. Could someday "mobility providers" like Uber, and at the same time also car-rental companies, be brushed aside as soon as car manufacturers, eventually partnering with information technology companies, build and then rent out self-driving cars by the hour? Thinking through such scenarios and their foundations is the domain of structured strategic thinking, the first building block in model shown in Figure 1. For a TRIZ practitioner who supports a strategy team, it is thus important to understand that mastery in the application of the Ideal Final Result can help a team converge the many findings into a vision or into scenarios. Yet, these skills need to be complemented by methods for the divergent strategic thinking phase.

4. Preliminary implications for the TRIZ practitioner's contribution to strategy creation teams

As has been shown by Kai Yang, there is a significant overlap between specific strategies and inventive principles. We have come to similar conclusions when comparing the application of the Ideal Final Result in TRIZ to the creation of a vision in strategy work. We also don't expect that result to change when more TRIZ approaches are studied for their applicability in strategy. TRIZ methods can therefore be considered a valuable approach to strategy creation.

At the same time, one must also bear in mind Kai Yang's observation that both Altshuller's 40 inventive principles and Sun Tzu's 36 strategies can claim space for themselves. Our investigation allows for an interesting addition: When "prior art" for strategy creation, planning and execution is considered, the how-to methods for crafting an Ideal Final Result can turn into powerful methods for crafting a vision.

In our view it will thus be interesting to explore how other TRIZ methods are similar to strategy creation tools and vice

versa: what TRIZ thinking can be found in strategy creation tools; however, that is outside the scope of this paper.

For as much as the findings discussed so far allow to conclude, the TRIZ practitioner should also enter the domain of strategy creation with caution and, as we'd like to say, with a humble attitude. As we have seen with Kai Yang's work, TRIZ and strategy can each claim space for itself and TRIZ can thus not be regarded as "holistic". Also, language shapes thinking and culture. Therefore, TRIZ practitioners have a carefully worded definition of the terms they employ. In the domain of strategy, the understanding of the same terms may be different – or it may simply be less well-defined and the TRIZ practitioner then needs to be able to recognize and to work in that environment. Furthermore, for the practice of strategy, not only a well-rounded business vocabulary but also fluency in a specific type of business language is required in order to be accepted as part of the "in crowd" in the boardroom.

Last but not least, a high tolerance for and even the embracing of different world-views appears equally important. If TRIZ can be seen as a strong analytical approach to problem solving, then the practitioner's contribution to a given team may well be judged upon his or her ability to complement and enhance the thinking of that team, The types of personalities and conversations, the "artifacts" created during that work and last, but not least, the team's very assessment of what a valuable input or output is may differ from what a TRIZ practitioner takes for granted.

Further investigations, namely by looking at other TRIZ and strategy creation approaches, may refine and make more specific these guidelines. We hope that will allow strategy practitioners to source from the powerful body of knowledge and the expertise available in the TRIZ community, and also help TRIZ practitioners to expand their influence into arguably one of the most impactful domains of organizational activities.

References

[1] Tzu, Sun. The Art of War. United States: Nabla; 2010 ed. [500 B.C.].

[2] Thucydides. History of the Peloponnesian War. London: Penguin Classics; 1972 ed. [400 B.C.].

[3] Dharma, Krishna, editor. Mahabharata. Torchlight Publishing; 1999 ed. [400 B.C.].

[4] Freedman, Lawrence. Strategy: A History. New York: Oxford University Press; 2013.

[5] Yang, Kai. TRIZ with China's 36 Strategies. The TRIZ Journal. 2010 Jan 4. Available from: https://triz-journal.com/inventive-principles-of-triz-with-chinas-36-strategies.

[6] McChyrstal, Stanley. Team of Teams. New York: Portfolio/Penguin; 2015.

[7] Lai, David. Learning from the Stones. Carlisle: Strategic Studies Institute, U.S. Army War College; 2004.

[8] Young, Emma. Chess! What is it good for? The Guardian. 2004 Mar 3. Available from: https://www.theguardian.com/science/2004/mar/04/2.

[9] Martin, Roger. Stop Distinguishing Between Execution and Strategy. Harvard Business Review. 2015 Mar 13. Available from: https://hbr.org/2015/03/stop-distinguishing-between-execution-and-strategy.

[10] Rumelt, Richard. Good Strategy Bad Strategy. New York: Crown Business; 2011.

[11] Waldo, Wes. The 7 Steps of Hoshin Planning. BMGI. 2013 Oct 10. Available from: https://www.bmgi.com/resources/articles/seven-steps-hoshin-planning.

[12] Ulwick, Anthony. What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services. United States: McGraw-Hill Education; 2005.

[13] Porter, Michael E. On Competition. Boston: Harvard Business School Publishing; 2008.

[14] The Growth-Share Matrix. BCG Perspectives. 2014 Jun 4. Available from: https://www.bcgperspectives.com/content/articles/corporate_strategy_portfolio_management_strategic_planning_growth_share_matrix_bcg_classics_revisited.

[15] Osterwalder, Alexander; Pigneur, Yves. Business Model Generation. Hoboken: John Wiley & Sons; 2010.

[16] Gassman, Oliver et al. The Business Model Navigator. Harlow: Pearson Education Limited; 2014.

[17] Samuel, Phil; Ohler, Michael. Classification of TRIZ Techniques Using a Cognition-Based Design Framework. Procedia Engineering. 2015; 131:984-992.

[18] Prahalad, C.K.; Hamel, Gary. The Core Competence of the Corporation. Harvard Business Review. 1990, May-June.

[19] Davenport, Thomas; Harris, Jeanne. Competing on Analytics. United States: Harvard Business School Publishing Corporation; 2007.

[20] Schwab, Klaus. The Fourth Industrial Revolution. Cologny/Geneva: World Economic Forum; 2016.

[21] Brown, Tim. Design Thinking. Harvard Business Review. 2008, June.

[22] Kristiansen, Per; Rasmussen, Robert. Building a Better Business Using the LEGO SERIOUS PLAY Method. Hoboken: John Wiley & Sons; 2014.

[23] Hohmann, Luke: Innovation Games: Creating Breakthrough Products Through Collaborative Play. United States: Addison-Wesley; 2007.

[24] Kim, W. Chan; Mauborgne, Renee. Blue Ocean Strategy. Boston: Harvard Business School Pubishing Corporation; 2005.

[25] Christensen, Clayton; Anthony, Scott; Berstell, Gerald; Nitterhouse, Denise. Finding the Right Job For Your Product. MIT Sloan Management Review. 2007 Apr 1. Available from: http://sloanreview.mit.edu/article/finding-the-right-job-for-your-product.

[26] Hentschel, Claudia. Design Thinking as a Door-Opener for TRIZ – Paving the Way for Systematic Innovation. Paris: Proceedings of the TRIZ Future Conference; 2013.

[27] Twain, Mark. The Adventures of Tom Sawyer. In: Chapter Two. 1876.

[28] Ulwick, Anthony; Bettencour, Lance. Giving Customers a Fair Hearing. MIT Sloan Management Review. 2008 Apr 1. Available from: http://sloanreview.mit.edu/article/giving-customers-a-fair-hearing.

[29] Leonard, Dorothy; Rayport, Jeffrey. Spark Innovation Through Empathic Design. Harvard Business Review. 1997, November-December.

[30] Beyer, Hugh. Contextual Design: Defining Customer-Centered Systems. San Diego: Academic Press; 1998.

[31] Ulwick, Anthony. Turn Customer Input into Innovation. Harvard Business Review. 2002, January.

[32] Wilkinson, Angela; Kupers, Roland. The Essence of Scenarios: Learning from the Shell Experience. Amsterdam: Amsterdam University Press; 2014.

[33] Barker, Joel. The Power of Vision [DVD]. 2005.

[34] Botswan, Rachel; Rogers, Roo. What's Mine Is Yours: The Rise of Collaborative Consumption. New York: HarperCollins; 2010.

[35] Circular Economy Strategy. European Commission. Available from: http://ec.europa.eu/environment/circular-economy

Towards Experience Capitalization for Inventive Problem Solving

Pei ZHANG[a,b,*], Cecilia ZANNI-MERK[b,c], Denis CAVALLUCCI[a,c]

[a]*LGeCo (Design Engineering Laboratory). Strasbourg, 67000, France*
[b]*SDC Team, ICube (UMR CNRS 7357), Strasbourg, 67412, France*
[c]*INSA de Strasbourg. 24 boulevard de la Victoire, Strasbourg, 67084, France*

* Corresponding author. *E-mail address:* pei.zhang@insa-strasbourg.fr

Abstract

In this paper, we propose a framework to represent an engineering case (the inventive problem solved using TRIZ methodology) in terms of IDMItem (Inventive Design Method Item) utilizing Set of Experience Knowledge Structure (SOEKS) as a knowledge representation to capitalize and reuse inventive design experience. TRIZ is a systematic problem solving methodology but the usage of it often requires expertise thus difficult for novel users, especially at a high level of abstraction. Besides, the impossibility of recording information and rules related to problem solving results in the inefficiency and duplication thus wastes valuable resources such as time. Therefore, in this paper, we explore the implementation of IDMItem with SOEKS which will provide the possibility of the capitalization of experience that will support more efficient and simpler problem solving.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: Inventive Design; TRIZ; Experience; Knowledge Representation; Set of Experience Knowledge Structure (SOEKS).

1. Introduction

The emerging necessity to support innovation with reliable methods and tools is a global trend among all continents. It concerns not only industry but also social and academic worlds. One of the most struggling bottlenecks for sustainable innovation is to concentrate on an efficient invention step. This unavoidable step in the creation of new objects currently only depends on people's creativity.

A successive innovation activity involves a series of tasks. During this process, there generates vast amount of valuable information. However, due to the lack of knowledge management support, this kind of information are often neglected or processed inefficiently. Therefore, it wastes important resources such as time. If the problem reoccurs, the problem solving process has to be repeated all over again. Furthermore, within the scope of TRIZ methodology, the mapping between problem and solution differs significantly due to the designers past experiences. For example, the mapping between the specific problem to the generic problem using contradiction matrix requires expertise. Thus makes it difficult to use for novel users.

To remedy these limitations, there emerges the research challenge to store and reuse experience in a persistent, formal manner to ensure the efficiency and to ease the solution facilitation for TRIZ novice. Previous work of the author [1] has developed an inventive problem solving platform based on ontology and semantic technologies. This kind of information should be collected, linked and reasoned to facilitate experience capitalization that would support more efficient and simpler problem solving. Among the recent knowledge representation techniques, we are interested in using Set of Experience Knowledge Structure (SOEKS) to capitalize previous experience.

SOEKS has been successfully used in the field of robotics [2], medical science [3] and manufacturing domains [4] to support decision making. However, there is no precedent research on using SOEKS to capitalize experience of inventive problem solving for a less time consuming invention step which is the novelty of this research.

In this paper, we define the term *IDMItem* (Inventive Design Method Item) as knowledge representation of an engineering case (the inventive problem solved using TRIZ methodology). It comprises the problem and the solution part which embeds decisional model stored by set of experience structure of human decisional activity. We propose an approach that integrates *IDMItem* with SOEKS as a knowledge representation to capitalize and reuse inventive design experience. In addition, an illustrative case study is given to demonstrate how *IDMItem* has the ability to support efficient decision making by the capitalization of previous experience.

This paper is organized as follows: section two describes the TRIZ problem solving method and Set of Experience Knowledge Structure; section three demonstrates implementation of the Decisional DNA applied to *IDMItem*; section four give an illustrative case study of our approach. Finally, section five discusses concluding remarks and future work.

2. Background

2.1. The TRIZ problem solving method

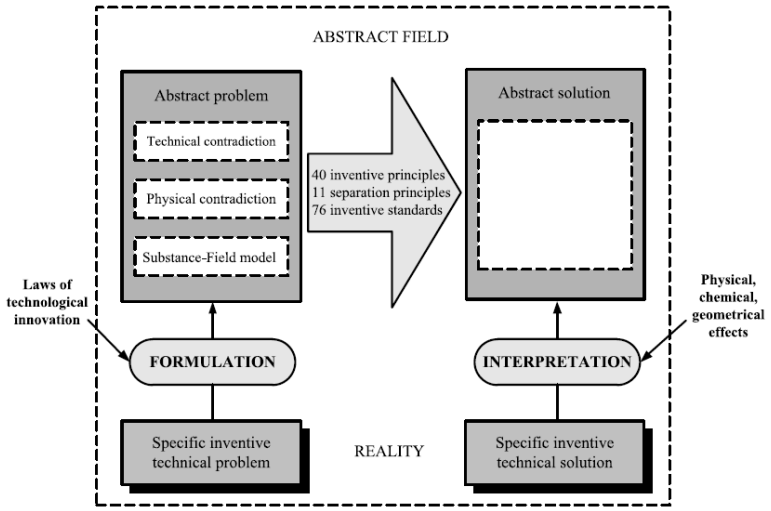


Fig.1. The TRIZ problem solving method

Fig 1 describes the way classical TRIZ solves problems, and the interrelations among its different parts. Three different phases are clearly identified:

- The “formulation” phase, where the expert uses different tools to express the problem in an abstract form, by the use of several models at different levels of abstraction.
- The “abstract solution finding” phase, where access to different knowledge sources is made to get one or more solution models.
- The “interpretation” phase, where these solution models are instantiated by human experts or with the help of the Physical Chemical Geometrical effects knowledge base to search for new scientific principle of a solution if it is needed, to get solutions to be implemented in the real world.

Previous effort has been made with the development of IngeniousTRIZ system to facilitate the problem solving process [5]. On the one hand, according to the TRIZ knowledge sources ontologies, this system provides users with relevant knowledge sources of the problem model they are building. On the other hand, the system has the ability to fill ‘‘automatically’’ the models of the other knowledge sources.

In the framework of IngeniousTRIZ system, there are two ways to go to facilitate the resolution: one is the inventive principles for elimination of technical contradictions; the other is the search of heuristic physical effects with the implementation of Su-field analysis.

2.1.1 Inventive principles for elimination of technical contradictions

This is the short path to conduct the resolution with the use of the contradiction matrix and the inventive principles. Following this path, the appropriate inventive principles can be obtained for the specific cases. In this phase, the user works with the

contradiction matrix and the inventive principles to obtain the abstract solution. Firstly, the user needs to provide the evaluation parameters and values to formalize the technical contradiction. In order to use contradiction matrix, parameters describe the specific problem (Evaluation parameters) need to be matched with 39 generic engineering parameters (GEPs). Then, the most similar GEPs are obtained through semantic search for each Evaluation Parameter. The user has to select which one he thinks is the most appropriate one. And based on the two selected GEPs, a series of inventive principles (up to 4) are obtained. And finally, the user has to choose again which Inventive Principle to use according to the specific characteristics of the case. However, the use of inventive principles to solve a technical contradiction is on a high level of abstraction, and it requires a huge effort for human interpretation. Moreover, if a problem is formulated into a contradiction, the resolution has to be performed by the use of inventive principles, there is no chance to browse the Effects database where there requires less interpretation effort. Because TRIZ knowledge sources are built on different abstract levels. Therefore, IngeniousTRIZ provided a second path to fill ‘‘automatically’’ the models of the other knowledge sources to be able to start with a problem formulated on the high level of abstraction and to facilitate the solution that is on the low level of abstraction, therefore, requires the minimum effort of interpretation.

2.1.2 The search of heuristic physical effects with the implementation of Su-field analysis

This is the long path which requires lower effort in terms of interpretation. For this long path, the TRIZ users are guided to search heuristic physical effects to help instantiate concept solution. The users start solving inventive problems with 40 inventive principles to obtain an abstract solution, and then, according to the selected inventive principles, the similar items of 76 inventive standards are obtained based on the semantic similarity calculated in advance. At this point, the user has to choose its most similar inventive standard for the specific case. With the help of the chosen inventive standard, the user is guided to implement Su-Field analysis. Firstly, the user needs to provide the basic information about the problem model, including two substances and a field. This information will be used to instantiate the inventive standards ontology in the process of ontology reasoning. Then, several related types of transformations are obtained based on the chosen inventive standards, from which the user needs to choose the appropriate one for the specific case. With the help of these similar items, the useful heuristic abstract solutions are obtained through the ontology inference. At the same time, the heuristic abstract solutions are created automatically suggesting the modification directions according to the specific case. Now the user has to decide which direction he wants to perform the modification (add/modify a substance; add/modify a field) and choose an appropriate way. And then, the user needs to provide the level of granularity for the element (substance or field) to be modified in order to implement the ontology reasoning. Finally, based on the information obtained above, the ontology inference with the rules is executed to generate the heuristic physical effects, which are stored in a new-built ontology. The user can select an appropriate physical effect for solving the specific problem.

As depicted in section 2.1.1, the short path of problem solving is simple but still stays on a pretty high level of abstraction. The use of inventive principles is difficult for the new users when attempting to map the various specific problem to a set of SPs to GEPs. The mapping process depends largely on human experience.

As depicted in section 2.1.2, the long path takes advantages of searching the physical effects database, which, in terms of solution interpretation, requires less effort. However, this path is much longer and requires human interaction which contains large amount of information that needs to be further explored.

Within these two problem solving processes, the human expertise plays an important role in terms of solution facilitation. Vast amount of valuable information within these paths must be captured and reused systematically for a more efficient innovation generation.

Having this in mind, this paper explores the use of Set of Experience Knowledge Structure (SOEKS) to capitalize knowledge coming from the elimination of technical contradictions as the first step of knowledge exploitation and reuse for inventive design method.

2.2. Set of Experience Knowledge Structure (SOEKS)

SOEKS is a dynamic structure that feeds on the formal decision events and uses it for the representation of experiential knowledge [6]. As decisional knowledge should be collected, we have to represent it in some form. One of the most complicated issues about knowledge is its representation. Representing knowledge determines how knowledge is acquired and transformed from tacit knowledge to explicit knowledge. The most generalized techniques of KR use logic, rules, or frames. A SOE (set of experience) comprises a series of mathematical concepts (a logical component), together with a set of rules (a rule based component), and build upon a specific event of decision-making (a frame component), thus makes it ideal for the representation of engineering design experience. The four components of a SOE that are used to describe a decision event are: variables, functions, constraints and rules, as shown in Fig 2. Variables are the basic component that a SOE is composed of and the foundation of the SOE structure. Functions characterize the meaningful connections connected input values. Constraints can be viewed as a special kind of function that limits the space of possible solutions. Rules allows the description of conditional relationships that operate in the universe of variables. Rules are relationships between a condition and a consequence connected by the statements “if−then−else”[7].

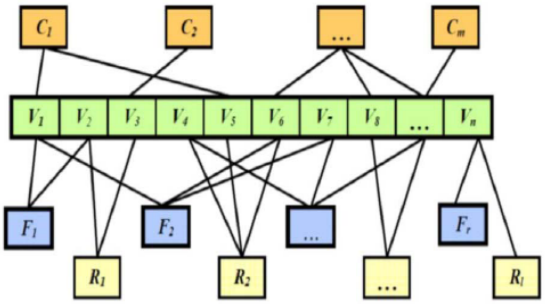


Fig.2. Set of Experience Knowledge Structure [8]

3. Implementation of an IDMItem

3.1. IDMItem

An IDMItem is a knowledge representation of an engineering case. It comprises the problem and solution. It embeds a decisional model expressed by set of experience structure of human expertise. An IDMItem is a dynamic representation of inventive design activity. And it is capable of capturing, adding, storing, improving, sharing and reusing knowledge through experience in a way similar to human expert.

3.1.1 Gathering data

The problem is formulated in terms of a contradiction. There are several parameters that need to be specified at the first place:

- *Element*: part of a decomposition of the studied system having a sense with regards to the key parameters of network.
- *Action Parameters*: they represent parameters on which the designer has a capacity of state modifications.
- *Evaluation Parameters*: their nature lies in the capacity to evaluate the positive aspect resulting from a choice of the designer.
- *Qualitative Values*: they are used to qualify *action parameters* and each value has its opposite. Values are qualitative (*Qualitative Value*) in order to keep the model abstract enough to allow for the effective use of the TRIZ and IDM methodologies.

A contradiction is composed of two *half contradictions*, where the same *action parameter* with both its opposite *qualitative values* needs to be considered and the same two *evaluation parameters* are involved. Therefore, to distinguish the two *half-contradictions* for the same contradiction we define *Half contradiction* and *Other half contradiction* to represent one complete contradiction.

3.1.2 Two Half contradictions

A *Half contradiction* is the situation where a value given to an *action parameter* has a *positive influence* on an *evaluation parameter*, but a negative one on another *evaluation parameter*. In the *Half contradiction* section, as shown in Table 1, the variables which formulate a *half contradiction* are stored as *Action Parameter*, *Evaluation Parameter*, *Qualitative Value* and *Influence*. Additional variables like *Case No.*, *HC Number*, and *Case Name* are stored to identify the *Half contradiction*.

The constraints are *Influence* which can be positive or negative and the *Qualitative Value* can be either one of the opposite value that characterize the contradiction. This is because the *Half Contradiction* and *Other half contradiction* are stored flexibly, but each of them is stored separately to ensure the complete description of a contradiction. This aspect is further ensured by the rules.

Take the hammer case as an example, if the *action parameter* "height between nail's head and anvil contract surface" is "high", then the "Ergonomy" *evaluation parameter* is affected positively, but the "Confidence" deteriorates. (*Half Contradiction*)

If the *action parameter* "height between nail's head and anvil contract surface" is "low", then the "Confidence" *evaluation parameter* is affected positively, but the "Ergonomy" deteriorates. (*Other Half Contradiction*)

The complementary *half contradiction* to the one in this example would be: for a high (*Qualitative Value*) height between nail's head and anvil contract surface (*Action Parameter*) of the hammer, there is a positive influence (*Positive Influence*) on "Ergonomy" (*Evaluation Parameter*) but a negative influence (*Negative Influence*) on "Confidence" (the other *Evaluation Parameter*).

3.1.3 Matrix

The *inventive principles* can be used in a systematic way by accessing the principles through indices in TRIZ Contradiction Matrix [9]. Along the vertical axis of this matrix the *improving parameters* are specified. Along the horizontal axis the *degrading*

parameters as a result of the improvement are specified. These parameters can be looked up along the vertical and horizontal axes and the matrix suggests up to four principles that can be used to solve the contradiction.

The variables in the *Matrix* part stores the number and the geometry information of the generic engineering parameters in TRIZ contradiction matrix, the parameter along the vertical axis is stored as the *Improving parameter* and the parameter along the horizontal axis is stored as the *Degrading parameter*. The constraints define the values of the 39 generic engineering parameters and the rules declares the systematic use to locate the cell which contains the *Inventive Principles*.

3.1.4 Solution

Variables in the *Solution* part stores the information related to the *concept solution* generation, including the *Inventive principle*, *Inventive principle number* the *Concept solution* designed by experts.

3.2. Building the network for knowledge extraction

For this case study, we consider four cases and efforts are made to store the data according to the SOEKS format. Once the *IDMItem* of the cases are developed, the network of the interactions is established. These interactions are based on the connections made in the *Interaction* part. The network links the *Evaluation parameter* with its corresponding generic engineering parameter in each *Half contradiction* and the interactions of the *Matrix* is represented in the network as well (Fig 3).

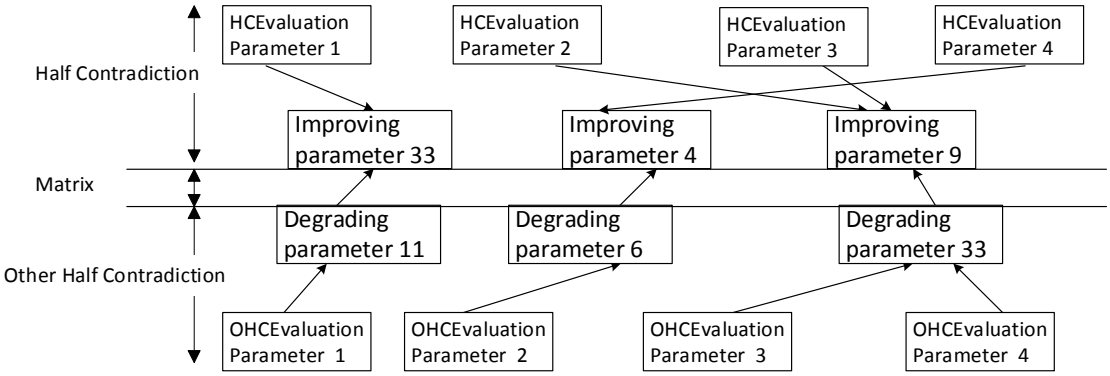


Fig.3. The network of interacted IDMItems

3.3. Experience collection

The *Experience* part is connected with other parts like *Half contradiction*, *Other Half contradiction*, *Matrix*, *Solution* and *Interaction* and is used to capture and store new information. *Experience* contains the knowledge and experience acquired about every solved inventive problem in a period of time.

A case study is given to illustrate how to apply the proposed knowledge representation method into case representation and record formal decision events (the point where a concept solution is generated). Table 1 illustrates the detailed architecture of a design component for design cases.

Table 1. *IDMItem* Architecture (Based on [10]).

	Variables	Functions	Constraints	Rules
Half contradiction	Case No. HC Number Case Name HCElement HCAction Parameter HCEvaluation Parameter HCQualitative Value HCInfluence		HCInfluence={positive influence, negative influence} HCQualitative Value ={high, low}	IF HCinfluence=positive influence AND HCEvalation parameter= Ergonomy AND HCQualitative Value=high THEN HCinfluence=negative influence AND HCEvalation parameter= Ergonomy AND HCQualitative Value=low

Other half contradiction	Case No. OHC Number OHCElement OHCAction Parameter OHCEvaluation Parameter OHCQualitative Value OHCInfluence	OHCInfluence={positive influence, negative influence} HCQualitative Value ={high, low}	IF OHCinfluence=positive influence AND OHCEvalation parameter= Confidence AND OHCQualitative Value=low THEN OHCinfluence=negative influence AND OHCEvalation parameter= Ergonomy AND OHCQualitative Value=high
Matrix	Improving parameter Improving parameter number Degrading parameter Degrading parameter number	Improving Parameter ={ Weight of moving object, Weight of stationary object,…,Productivity} Degrading Parameter ={ Weight of moving object, Weight of stationary object,…,Productivity} Improving Parameter Number={1,2,3,…39} Degrading Parameter Number={1,2,3,…,39}	IF Improving parameter = Ease of operation AND Degrading parameter= Stress or pressure, THEN Inventive principle = Taking out OR Color changes OR Equipotentiality IF Improving parameter number= 33 AND Degrading parameter number=11, THEN Inventive principle number=2 OR 32 OR 12
Solution	Case No. Case Name Inventive principle Inventive principle Number Concept solution	Inventive Principle ={Segmentation, Taking out, Local quality,…,Composite materials} Inventive principle Number={1,2,3,…,40}	
Interaction	Case No. Case Name ContradictionComponent MatrixComponent		
Experience	Case No. Case Name Half contradiction Other half contradiction Degrading parameter number Degrading parameter Improving parameter number Improving parameter Inventive principle No. Inventive principle Concept solution		

4. An illustrative example

Let us now consider a new problem with the same *Half contradiction* and *Other half contradiction* as the case we have already capitalized. The *half contradiction* is considered the same if they have the same *Evaluation Parameter*. The new case has the *HCEvaluation Parameter* “efficiency” and *OHCEvaluation Parameter* “ease of use”.

Before the capitalization of previous experience, the user has to follow the problem solving process again with IngeniousTRIZ system. As depicted in Fig.5, a stage-gate model is given to illustrate the comparison before and after experience capitalization. Before the experience capitalization, when there is a technical contradiction to solve, first the semantic similarity is calculated between the Evaluation Parameters and Generic Engineering Parameters. And then the five most similar Generic Engineering Parameters is obtained and the user has to match the corresponding Generic Engineering Parameters respectively. Next, the Inventive Principles are obtained based on the chosen GEPs. After this step, the user has to choose one Inventive Principle to facilitate concept solution. Next, the user designs a concept solution. Lastly, the result is saved by the system.

After the capitalization of the previous design experience, this process is evidently shortened by finding the previous experience that has the related knowledge in it. If the same *HCEvaluation Parameter* and the *OHCEvaluation Parameter* are both found, that means the previously solved problem is found, and the experience of this capitalized problem is obtained (see Fig. 4, Table 2). The capitalized experience could be reused for the new case which has the same *HCEvaluation Parameter* and *OHCEvaluation Parameter*. The *inventive principle* could be obtained directly because of the previously capitalized experience. The related information and their relation with *IDMItem* are stored in the *Interaction* part.

The user could be greatly inspired by the previous experience that has already capitalized. Skipping the procedure that leads to the *inventive principle* and the *concept solution* that has been previously used by designers for problem solving improves the efficiency and ease the use of TRIZ to non-experts.

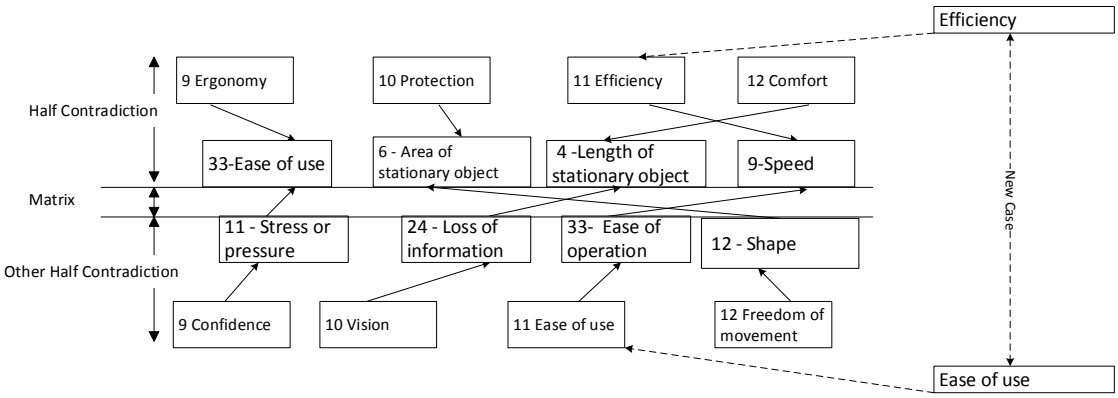


Fig.4. The new problem with the same evaluation parameters and the capitalized case

Table 2. An example for *IDMItem* Experience (based on [11]).

Variables

Case No.	Case Name	Half contradiction	Other half contradiction	Degrading parameter number	Degrading parameter	Improving parameter number	Improving parameter	Inventive principle No.	Inventive principle	Concept solution
11	Rasor	HC 11	OHC 11	9	speed	33	Ease of operation	13	The other way around	Increase the layers of razor instead of increasing length

Constraints

Degrading parameter number= {1,2,3,…39}

Improving parameter number={1,2,3,…39}

Improving Parameter ={ Weight of moving object, Weight of stationary object,…,Productivity}

Degrading Parameter ={ Weight of moving object, Weight of stationary object,…,Productivity}

Inventive Principle ={Segmentation, Taking out, Local quality,…,Composite materials}

Inventive principle No.={1,2,3,…,40}

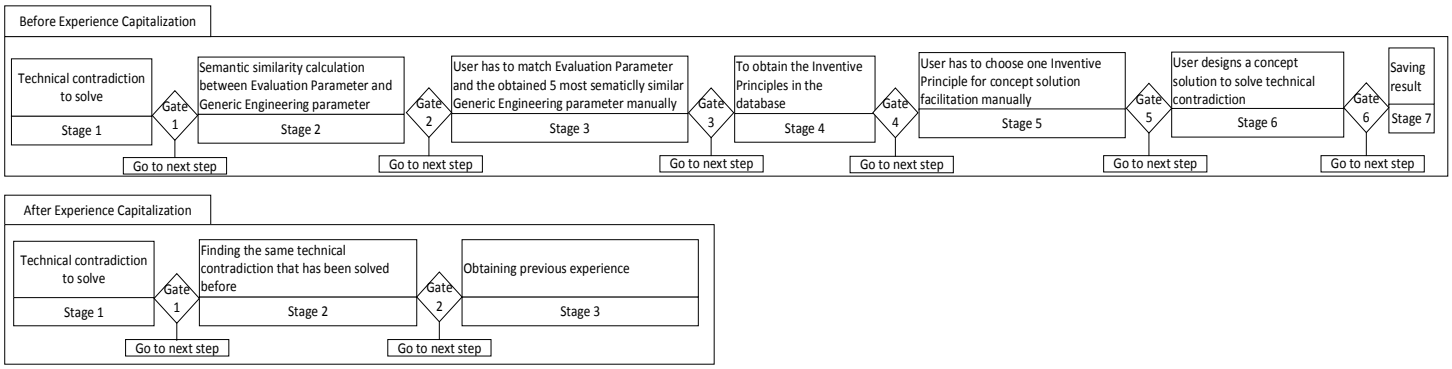


Fig.5. Comparison before and after experience capitalization

5. Conclusion and future perspectives

In this paper, we implemented SOEKS to *IDMItem* to capture and store formal decision events coming from technical contradiction elimination as explicit knowledge. The experience capitalization allows the reuse of existing solutions. When the same problem needs to be solved, SOEKS reuse the previous experience that they find to solve the same problem. It has the advantage of reducing problem solving time, avoiding repetition and duplication in problem solving process.

This experience capitalization of technical contradiction elimination serves as the first step as the efficient use of experience. This temptation would give rise to the experience capitalization of the other branch of the IngeniousTRIZ system where there is opportunity to search from effects database to get heuristic solutions. Therefore, the SOEKS experience base is expected to be more exhaustive with resolution coming from the direct use of inventive principles and effects.

After this, we could further add the axes of flexibility to add adaptability to reuse the previous experiences with Case-based reasoning (CBR) to enrich SOEKS for future research. As it has been explained in this paper, the use of classical SOEKS compared and reused the exactly the same case that is in the SOEKS base directly with no adaptation. Case-based reasoning adopts validated prior experience, as solution to solve a new problem [12]. Beginning from 1980s, CBR development has led to many successful applications aiming at exploiting knowledge from expertise in different domains, some examples would be the HYPO system of law[13], civil engineering [14] and marketing [15]. In the engineering domain, CBR works by constructing a case base that contains a number of cases which has been successfully solved by experts. When CBR is used to solve a new problem, firstly the new problem is represented according to SOEKS. Then similar problems are retrieved from the case base, and the solution of the most similar problem is suggested for the new problem. If it is necessary, this suggested solution is revised according to previous experience, domain knowledge and the actual situation of the new problem, and the system learns along with the use. So that the next time a case that are similar to the previously solved ones, instead of proposing the exact capitalized solutions, similar cases are retrieved and the solution of the similar cases could be adapted to generate new solution to a new case. Thus, the use of CBR introduces the flexibility axes to the research. At this point, several research question appears that needs to be further discussed: what is the notion of similarity between two cases? How to preform similarity metrics for each element of a SOE that has unique characteristics? And how to combine their separate results to perform case retrieval? In which way to adapt the solution to solve the new problem? These are still open questions that require further research.

References

[1] W. Yan, “(Meta) Knowledge modeling for inventive design,” Université de Strasbourg, 2014.

[2] H. Zhang, C. Sanin, and E. Szczerbicki, “Decisional DNA Applied to Robotics,” in *Knowledge-Based and Intelligent Information and Engineering Systems*, R. Setchi, I. Jordanov, R. J. Howlett, and L. C. Jain, Eds. Springer Berlin Heidelberg, 2010, pp. 563–570.

[3] E. Sanchez, C. Toro, E. Carrasco, P. Bonachela, C. Parra, G. Bueno, and F. Guijarro, “A Knowledge-based Clinical Decision Support System for the diagnosis of Alzheimer Disease,” in *2011 13th IEEE International Conference on e-Health Networking Applications and Services (Healthcom)*, 2011, pp. 351–357.

[4] S. I. Shafiq, C. Sanin, C. Toro, and E. Szczerbicki, “Virtual engineering process (VEP): a knowledge representation approach for building bio-inspired distributed manufacturing DNA,” *Int. J. Prod. Res.*, pp. 1–14, 2015.

[5] W. Yan, H. Liu, C. Zanni-Merk, and D. Cavallucci, “IngeniousTRIZ: An automatic ontology-based system for solving inventive problems,” *Knowl.-Based Syst.*, vol. 75, pp. 52–65, Feb. 2015.

[6] S. I. Shafiq, C. Sanín, and E. Szczerbicki, “Set of Experience Knowledge Structure (SOEKS) and Decisional DNA (DDNA): Past, Present and Future,” *Cybern. Syst.*, vol. 45, no. 2, pp. 200–215, 2014.

[7] C. A. M. Sanín, *Smart knowledge management system*. University of Newcastle, 2007.

[8] E. Szczerbicki, C. Sanin, and S. I. Shafiq, “Set of experience and decisional DNA: Toward brains for cyber-physical systems and industry of the future,” in

Cybernetics (CYBCONF), 2015 IEEE 2nd International Conference on, 2015, pp. 7–11.

[9] G. S. Al′tshuller, L. Shulyak, and S. Rodman, *The Innovation Algorithm: TRIZ, Systematic Innovation and Technical Creativity*. Technical Innovation Center, Inc., 1999.

[10] S. I. Shafiq, C. Sanin, E. Szczerbicki, and C. Toro, "Implementing Virtual Engineering Objects (VEO) with the Set of Experience Knowledge Structure (SOEKS)," *Procedia Comput. Sci.*, vol. 35, pp. 644–652, 2014.

[11] S. I. Shafiq, C. Sanin, E. Szczerbicki, and C. Toro, "Virtual engineering objects: Effective way of knowledge representation and decision making," in *New trends in intelligent information and database systems*, Springer, 2015, pp. 261–270.

[12] F. Rousselot and J. Renaud, "On Triz and Case Based Reasoning Synergies and Oppositions," *Procedia Eng.*, vol. 131, pp. 871–880, 2015.

[13] K. D. Ashley and E. L. Rissland, "A case-based approach to modeling legal expertise," *IEEE Intell. Syst.*, no. 3, pp. 70–77, 1988.

[14] I. Watson and S. Abdullah, "Developing case-based reasoning systems: a case study in diagnosing building defects," in *Case Based Reasoning: Prospects for Applications (Digest No. 1994/057), IEE Colloquium on*, 1994, pp. 1–1.

[15] S. W. Changchien and M.-C. Lin, "Design and implementation of a case-based reasoning system for marketing plans," *Expert Syst. Appl.*, vol. 28, no. 1, pp. 43–53, Jan. 2005.

TRIZ-based analysis of the rail industry problem of low adhesion

John Cooke

Cocatalyst Limited, 30 Salisbury Road, Farnborough, GU14 7AL, UK

Tel.: +44 796 6920 595; *E-mail address:* john@cocatalyst.com

Abstract

For many years the rail industries in temperate countries have struggled to deal with the effects of low adhesion between the train wheels and track due to leaf fall in the autumn – the so-called problem of "leaves on the line". During autumn, it is common in the UK for this problem to lead to journey delays and in some cases even service cancellations. Significant costs are incurred by the rail industry to manage and mitigate this problem; common measures include vegetation removal, track sanding units on all trains, special trains to clean the tracks and even special autumn timetables with increased journey times. The Rail Standards and Safety Board (RSSB), a UK rail industry coordinating body, decided to commission a TRIZ-based study into the problem of low adhesion. They were concerned that the solutions being considered by the industry at that time were limited in scope and hoped that TRIZ might help them to re-focus their work and find new areas for research. This paper outlines the process followed during the study, revealing key insights derived from the TRIZ analysis into the problem as well as the main conclusions and recommendations. So far, the outputs of the study have been directly used to support and focus two UK rail industry competitions: a 100% funded £225k academic research call and a 100% funded £4m UK small business focused competition entitled Predictable and Optimised Braking for Rail Vehicles. The scope of the successful project proposals for each was significantly broader than for previous (non-TRIZ-assisted) competitions.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: TRIZ; Horizon Scanning; Low Adhesion; Rail Industry; Cause-Effect Analysis; Process Mapping; System Conflicts; Conflict Resolution;

1. Background to the low adhesion problem

Low adhesion is a long standing and costly problem for the UK rail industry. When a train driver applies the brakes of a train approaching a signal or station, the greatly reduced rate of train deceleration under certain rail conditions can lead to an increased occurrence of safety related incidents, requiring many expensive mitigation measures to be used. The problem is compounded as the braking performance of the train in low adhesion conditions is often very difficult to predict. Low adhesion occurs most frequently in autumn and spring and is thought to be the result of external contamination (for example tree leaves) between the rail and wheel. As train drivers cannot be sure where low adhesion might occur they tend to adopt a more conservative braking strategy when they believe there is a higher risk, resulting in increased and unpredictable journey times between stops. Even though the UK rail industry issues a special autumn timetable with longer allowed journey times, low adhesion is often cited as the cause of service train delays.

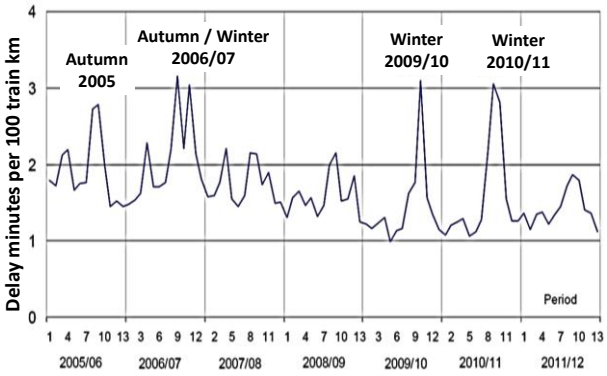


Fig. 1. Delay minutes per 100 train km 2005 to 2012 [1].

Figure 1 shows a UK rail industry graph for late train arrival (delay minutes) between 2005 and 2012 which

demonstrates the seasonal variation in railway performance. The highest delays generally coincide with the times of highest leaf fall.

If the problem of unpredictable low adhesion is not resolved it is set to become an even more critical issue in future, with the planned introduction of ERTMS (the European Rail Traffic Management System) and possible fully-automated train operation (e.g. driver-less trains). For example, ERTMS must make an assumption of expected braking rates; if these have to be made more conservative to allow for the effects of low adhesion, the distance between trains must increase and the capacity of the rail network is greatly reduced.

Before the TRIZ-based study was commissioned, most low adhesion related research activity in the UK focused on topics such as friction modification systems – e.g. improved traction gels [2], changes to Wheel Slide Protection systems [3] and better ways detect low adhesion – e.g. by monitoring running conditions on-board a rail vehicle [4]. Over the years many solutions have been attempted and a large amount of research into the causes of low adhesion at the wheel-rail interface has taken place, for example [5, 6, 7]. In spite of this work, low adhesion events were still common across the UK rail network and there was no consensus on the best way to deal with the issue. RSSB wanted to find out if a TRIZ-based approach might help the UK rail research community to "think outside of the rail industry box". The primary purpose of the study was therefore to review the low adhesion research and existing rail industry solutions from a TRIZ perspective, enabling "knowledge gaps" to be uncovered and potentially interesting solution directions to be identified.

1.1. TRIZ-based Horizon Scanning process

A six-step horizon scanning process was used to investigate the problem of low adhesion, combining various TRIZ tools to generate a shortlist of promising technologies and solutions. Figure 2 shows the overall steps in this process.

Fig. 2. A six-step horizon scanning process

The following section describes the activities contained within each process step in greater detail.

1. Situation Analysis

The focus areas for the investigation are defined, critical success factors are listed and a "problem statement" is prepared. During this step, background information is gathered and a number of TRIZ tools (such as MPV analysis) are used to clarify and prioritise the work programme.

2. System Mapping

The system is mapped and sub-divided. Cause-Effect maps are produced, starting with sub-problems from the previous stage and working down to root problems. The problem and system is mapped as a process. The current system is positioned against the TRIZ trends of system evolution. At the end of this stage, a list of sub-problems is produced.

3. Conflict Formulation

A more detailed functional map is prepared showing the physical actions within the system. The output of this step is a list of root conflicts and disadvantages in the system. At the end of this stage the true barriers to a strong solution become clear.

4. Conflict Resolution

TRIZ tools (such as ARIZ and Substance-field modelling) are used to identify strong solutions and draw out physical principles, which, if used, can help to break through the barriers found in step 3. The required solutions and physical principles are written as function-based statements.

5. Concept Verification

TRIZ function oriented search methods are used to find technologies which make use of the required functions and physics. The resources already present within the problem situation are also analysed to find out if any of these could be used to deliver the required functions and physics. The output of this stage is a list of concept solutions and technologies.

6. Solution Selection

The technologies and concepts are reviewed against the success factors from step 1 and a technology and solution short-list is agreed. Concept illustrations are prepared to describe promising combinations of the short-listed technologies and solutions. The short-list is reviewed to uncover secondary conflicts; the problems which often stand in the way of applying a new technology.

1.2. Application of the horizon scanning process to the problem of low adhesion

The next part the paper shares some of the highlights of the low adhesion analysis taken from the relevant Horizon Scanning process steps. Certain aspects of the analysis have been omitted in the interest of brevity.

1.2.1. Situation analysis of low adhesion

The problem of low adhesion was broken down into "how to?" statements which were structured hierarchically to enable the scope of the work to be defined. It was agreed that the study would concentrate on the braking related aspects of the

low adhesion problem, in terms of both braking performance and predictability. This work produced the problem statement "how to ensure reliable, predictable braking?" Figure 3 shows the resulting problem map. Any out-of-scope areas are shown in boxes surrounded by dotted lines.

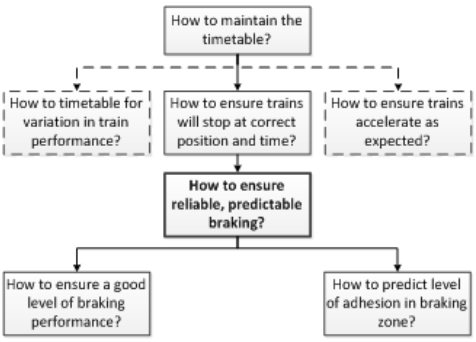


Fig. 3. Problem map for reliable, predictable braking

The corresponding problem description of "unpredictable, inconsistent braking" was used to provide the starting point for a top level cause-effect analysis, shown in figure 4. The cause-effect method [8, 9] enables the logic of the problem situation to be mapped and reviewed and ultimately helps expose root causes for the problem (shown in bold). Starting with the problem of "unpredictable, inconsistent braking" (shown in italics), lower level causes were identified. In cause-effect analysis, where more than one cause is required to produce an effect, this is shown by using an "AND" gate. Where any of a number of individual causes could each lead to an effect, an "OR" gate is used. Once again any agreed out of scope elements are shown in boxes surrounded by dotted lines.

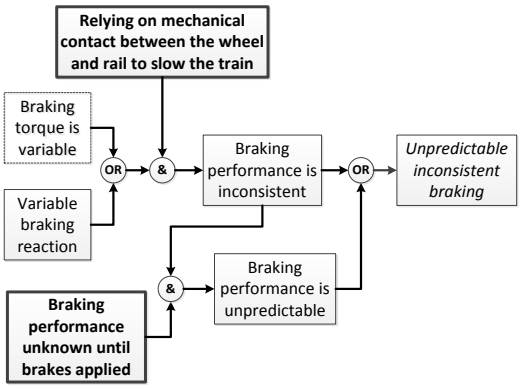


Fig. 4. Top-level cause-effect analysis of *"unpredictable, inconsistent braking"*

The cause-effect analysis highlighted the following basic insights:

- A key cause of braking unpredictability is the lack of consistent braking performance. If braking is consistently good, the need to predict braking poor performance disappears – by definition, consistent, effective braking is predictable braking. The logic of this connection is shown by the circular relationship between the two causes. The implication of this finding is that greater emphasis should be placed on solutions that are likely to deliver consistent, effective braking performance.

- Braking performance is unpredictable because there is no way of knowing what the likely braking performance will be until the brakes are applied. The on-board condition monitoring concept mentioned earlier [4] represents one possible way to address this issue.

- The fact that braking relies on mechanical contact between the wheel and railhead means that stopping performance is dependent on friction. In the past, the UK rail industry has considered but not implemented solutions such as eddy-current braking to by-pass the need for braking through the wheel-rail contact point.

1.2.2. System Mapping

During this step a more in-depth analysis was conducted into the causes of inconsistent braking performance.

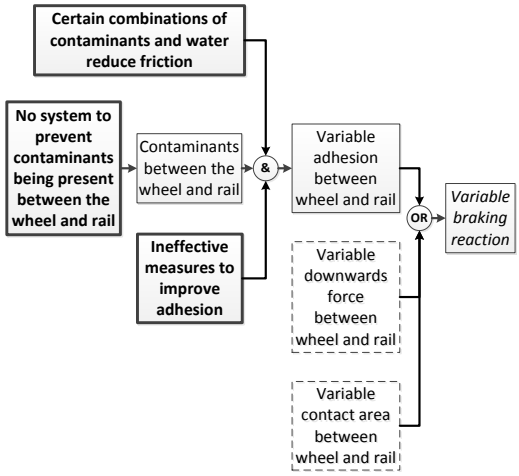


Fig. 5. Cause-effect map of *"Variable braking reaction"*

Cause-effect mapping was again used to provide a better understanding of the root causes behind *"Variable braking reaction"*. Figure 5 shows the resulting cause-effect map.

This diagram summarises three further conclusions:

- The current measures used to control low adhesion (such as train-mounted track sanding units, special trains to clean the tracks and the addition of various adhesion modifiers to the track) are largely ineffective. This finding is supported by the fact that the issue of low adhesion is still present even though all the mitigation measures are in use. When the occurrence of low adhesion events was analysed, the only correlating factors found were location, time of year and weather patterns.

- Although various methods (such as track-mounted aero-dynamic devices) have been tried in the past to stop contaminants arrival, none have been implemented on the UK rail network. This indicates the existence of other

conflicting requirements such as the need for any solution to support routine track maintenance.

- When certain contaminants, such as iron oxides, organic matter and water are present at a critical level on the rail the friction reduces significantly.

In order to understand the factors behind the contaminant-related friction reduction, a process map [10, 11] was prepared to show the "life cycle" of the low adhesion, leaf based coating on the rail – see figure 6.

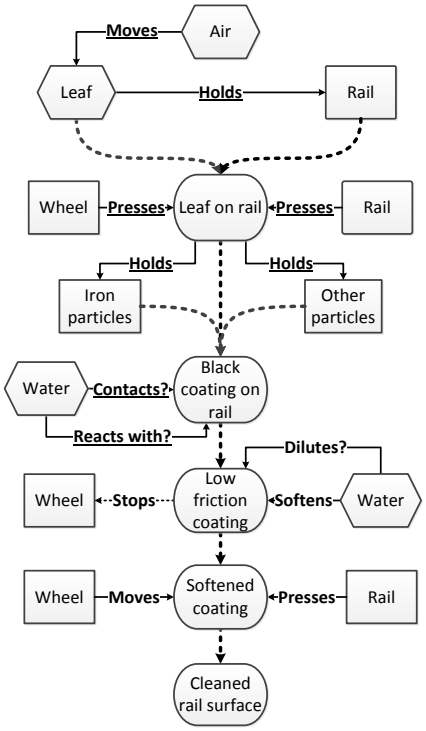


Fig. 6. Life-cycle process of the leaf-based low adhesion coating

The process map details the situation with no mitigation measures (e.g. water jetting, use of sanding or other adhesion modifiers) but includes environmental factors such as rain and wind. Airborne leaves are blown or drop from surrounding trees and arrive on the railway track. Passing trains squeeze the leaves between the train wheels and rails. The compressed leaf matter combines with other contaminants to form a hard black coating on the rail with very low frictional properties. If the rail is subjected to large amounts of water, the coating softens and is removed by the passage of later trains. The process map uses the same shape convention as for TRIZ function modelling - i.e. the target of the process (the leaf-based coating) is shown by using a rounded rectangle form. Any harmful actions are shown as <u>underlined</u> text.

The diagram highlights the following points:

- The role water plays in the creation and removal of the low friction rail coating is not straightforward. Previous rail industry studies showed that wheel-rail friction reduces greatly when a small amount of water is present. Although the physics behind this phenomenon is not clear, two hypotheses have been proposed. One hypothesis states that water combines with organic rail surface contaminants to create a high viscosity fluid layer between the wheel and rail; the other suggests that the water reacts with the iron oxide present in the coating resulting in a low friction iron oxide platelet layer [12].

- A large amount of water has a positive impact, softening and possibly "diluting" the coating on the rail.

- The amount of water present at the wheel-rail contact point is essentially uncontrolled

When this analysis was presented to rail industry subject matter experts, they could not explain how water influenced friction at the wheel-rail interface (with or without other contaminants). Research was subsequently commissioned to address this knowledge gap [13].

1.2.3. Conflict Formulation

This paper details the analysis of four specific sub-problems, representing key focus areas for RSSB, as follows:

- Ineffective measures to improve adhesion
- No system to prevent contaminants being present between the wheel and rail
- The amount of water at the contact point is uncontrolled
- Relying on mechanical contact between the wheel and rail to slow the train

1.2.3.1. Conflict Formulation for "ineffective measures to improve adhesion"

Earlier analysis showed that the existing mitigation measures are largely ineffective in controlling low adhesion. On-train sanding was said to be the most effective measure so this was selected for analysis.

In November 1994 a passenger train crashed into the buffers at Slough railway station after failing to stop. The cause was found to be low adhesion. As a result of this accident all UK rail trains are fitted with driver operated sanding systems to improve braking in low adhesion conditions. In general, the more sand deposited between the train wheels and rail, the greater the train deceleration can be. However, the amount of sand used is restricted by two main considerations; firstly, limited on-train storage capacity and secondly, the need to maintain good electrical conductivity between the train wheels and rails. The wheels and rails form part of the track circuit [14] which detects the presence of a train on a section of track. The conflict between track sanding and track circuit can be formulated as shown in figure 7:

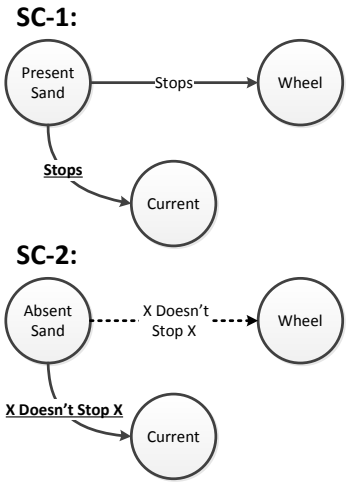


Fig. 7. System Conflict for on-train sanding and track circuit integrity

1.2.3.2. Conflict Formulation for "no system to prevent contaminants being present between the wheel and rail"

Special purpose water jetting trains are often used to remove contaminants from the rail in autumn. These trains deliver water onto the rail surfaces at high pressure and apply adhesion modifying paste. Over time the speed of this train has had to increase to reduce disruption to normal services. This indicates a conflict between the special purpose train and the overall rain network, shown graphically in figure 8:

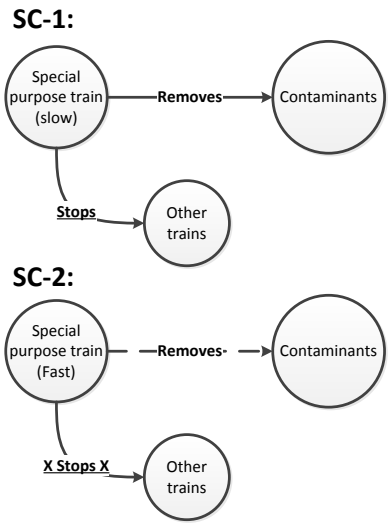


Fig. 8. System Conflict for water jetting train

1.2.3.3. Conflict Formulation for "the amount of water present at the wheel-rail contact is uncontrolled"

Strictly speaking this problem relates to a lack of control of a system component rather than a conflict. However, the reason why this lack of control exists is due to a long-standing underlying rail industry conflict.

During the late 1970s trials were run on the British railway network in which trackside water spraying systems were used to control the amount of water present on the rails [15]. The trials were run on a section of track where low adhesion problems were common. One section of track was subjected to water spraying while the opposite track was used as a control. Periodic friction measurements showed far higher results for the sprayed track than the control, confirming that trackside spraying could be effective in preventing low adhesion. In spite of the positive results, implementation was blocked due to concerns over the added complexity and management requirement such a solution would bring. This situation can be expressed as the conflict shown in figure 9.

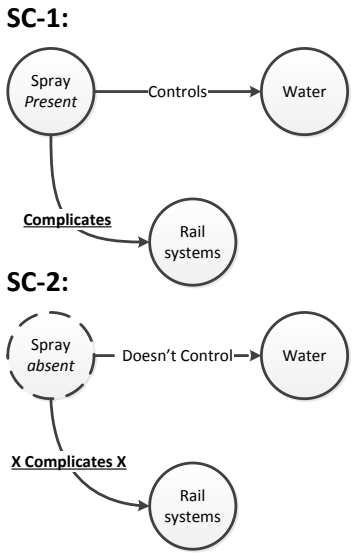


Fig. 9. System Conflict for trackside water spraying

1.2.3.4. Conflict Formulation for "relying on mechanical contact between the wheel and rail to slow the train"

There are a number of potential ways to by-pass the need for braking through the wheel-rail contact. The conflict analysis shown in this paper uses eddy current braking as its starting point because it offers the potential for significantly improved braking performance, albeit with drawbacks.

Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor, due to Faraday's law of induction. Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field. They can be induced within nearby stationary conductors by a time-varying magnetic field, or by relative motion between a magnet and a nearby conductor (as in the case of eddy current braking). Figure 10 shows how the eddy currents provide a braking effect. Eddy currents are induced in a conductive metal plate as it moves to the left under a magnet. The magnetic field (B) is directed down through the plate. The increasing field at the leading edge of the magnet (right) induces a clockwise current, which creates its own magnetic field (right arrows) directed upwards to oppose the magnet's field, producing a retarding force. Similarly, at the trailing edge of the magnet (left), an anti- clockwise current and downward counter-field is created (left down arrows) also

producing a retarding force.

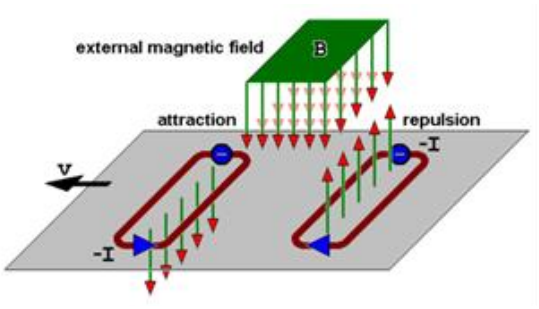


Fig. 10. Eddy current generation in a conductive metal plate.

The eddy currents generated in the conductor lead to resistive losses that transform kinetic energy into heat. To deliver a simple train braking solution, eddy currents must be generated in the rails, creating undesirable levels of heating. This issue has prevented the use of eddy current braking in many rail applications. Figure 11 summarises this situation.

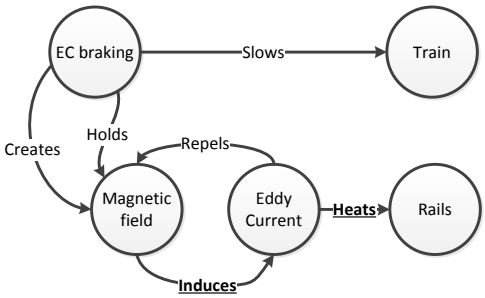


Fig. 11. Useful and harmful effects of eddy current braking.

When the components of the system are analysed further an interesting physical contradiction appears for the eddy currents in the rail, stated as follows:

PC-1: To provide the useful action "slows train", the eddy currents should be *present*.

PC-2: To eliminate the harmful action "heats rail" the eddy currents should be *absent*.

1.2.4. Conflict Resolution

Having formulated conflict statements for the four sub-problems, each area is now evaluated to understand the most appropriate conflict resolution direction.

1.2.4.1. Conflict Resolution for "ineffective measures to improve adhesion"

Continuing the analysis of the system conflict identified in step 3, it is clear that the useful function "sand stops wheel" should be preserved or increased while the harmful function "sand stops current" should be removed. Sand acts as an auxiliary tool correcting a problem in the basic system. TRIZ suggests that such components should be removed [15]. This leads to the following statement of the Ideal Final Result (see figure 12) in which the x-component is preferably an existing readily available system resource.

IFR
We need to introduce an X-component which stops the wheel without stopping the current flow

Fig. 12. Ideal Final Result (IFR) to resolve on-train sanding system conflict

The IFR is converted into a functional search statement for use in the next step of the analysis – *to resist relative movement between two objects without hindering current flow between them.*

1.2.4.2. Conflict Resolution for "no system to prevent contaminants being present between the wheel and rail"

Intensifying the conflict from the previous analysis leads to this statement: an infinite number of special purpose trains should be present everywhere to remove contaminants from the rail but there should be no special purpose trains at all to avoid delaying other trains. Once again this analysis shows that the special purpose train is an auxiliary tool which should be trimmed from the system. Existing system resources should be used to deliver the useful function "removes contaminants" only when needed during train braking. This strongly indicates that any contaminant removal system ought to be deployed on the braking train itself. Naturally, this conclusion leads to further secondary conflicts related to complexity, available space and cost.

1.2.4.3. Conflict Resolution for "the amount of water present at the wheel-rail contact is uncontrolled"

This conflict is similar to that stated for contaminant removal, indicating that trackside spraying should be removed and replaced by an existing system resource. Once again the braking train is a potentially suitable resource. Considering the interesting role played by water in this problem, the concept of a train-mounted controllable water delivery system emerges as a relatively simple way to improve train braking.

1.2.4.4. Conflict Resolution for "relying on mechanical contact between the wheel and rail to slow the train"

In the previous conflict formulation, a physical contradiction was stated for the eddy currents, which required them to be both *present* and *absent*. There are three basic ways to resolve these contradictory requirements:

Separate in space: The eddy currents are absent from the rail but present elsewhere. For example, braking could be delivered by a separate rail.

Separate between system and sub-system: The eddy currents are absent in the rail but are present in sub-elements of the rail. The rail is a monolithic structure, limiting options for segmentation (used in transformers to avoid power loss).

Separate in time: The eddy currents are present in the rail at one time and absent at another time. This leads to a conceptual solution in which the eddy currents are generated in the rail to provide retardation but are then "harvested" from the rail to avoid or minimize rail heating. This prompts the following functional search statement – *to induce and remove (harvest) electrical current flow in a conductor*.

1.2.5. Concept Verification

During this step, resource analysis [16] was used to understand available and potentially derived resources. Substance-field based morphological analysis broadened the scope of physical effects and technologies considered. A key-word search using the functional search statements was conducted. Some solutions even came from the rail industry – for example, a search based on the outputs from section 1.2.4.4, highlighted a recent research report by the Rail Technical Research Institute in Japan [17]. This paper presented a regenerative Linear Induction Motor braking system in which the eddy currents in the rail induce braking current flow in the main braking coils. A prototype of this solution reduced rail heating by more than 50% compared with eddy current braking. The UK rail industry subject matter experts were surprised by this development.

1.2.6. Solution selection

The research conducted in step 5 yielded a number of promising technologies and solutions. All the solutions were evaluated against the screening criteria which had been agreed during stage 1. A key criterion for any successful solution was the ability to guarantee a friction coefficient greater than 0.1. The most promising solutions were then clustered to create a list of main solution themes as follows:

1. Adding and/or modifying water at the rail wheel contact point
2. Better ways to remove contaminants from the rail
3. Use of controllable materials introduced around the contact point to enhance braking
4. Use of electromagnetic induction effects to enhance or replace braking through direct rail wheel contact

1.3. Conclusions

This paper shows that a TRIZ-based Horizon Scanning methodology can help "open up" important new areas of research. The study report detailed a range of potential solutions to the problem of low adhesion, many of which were "new" to the UK rail industry. The TRIZ-based Horizon Scanning method proved to be highly effective in exposing insights about the problem of low adhesion and in finding strong, actionable solutions. Over the last two years the following low adhesion related research studies have been completed (projects directly influenced by the TRIZ-based study shown in *italic*):

- *Modelling and quantifying the influence of water on wheel/rail adhesion levels*
- Improve rail wettability
- Towards a high resolution 'Internet of Things' moisture detection system for railways
- *Non-contact ultrasonic cleaning*
- *Linear induction motors for reliable braking*
- Optimised Brake System
- *Control of Wheel/Rail Interface Conditions using Dry-Ice Blasting*
- Consistent Rail Head Conditioning System for Optimised and Predictable Braking on Railways
- *Controlled water addition to improve braking performance in low adhesion conditions*
- *Zero wheel slip linear induction motor*
- *Summer braking all year round*

Research and technology demonstration work continues to progress on a number of these topics.

References

[1] Network Rail Annual Return 2012 – Section 1, Page 15.
[2] http://www.lbfoster.co.uk/_pdf/LBF-Traction-Enhancement.pdf
[3] http://www.rssb.co.uk/research-development-and-innovation/research-and-development/research-project-catalogue/t877
[4] http://www.rssb.co.uk/library/research-development-and-innovation/research-brief-t959.pdf
[5] Y. Zhu, U. Olofsson, K. Persson, "Investigation of factors influencing wheel–rail adhesion using a mini-traction machine", Wear, Volumes 292–293, 15 July 2012, Pages 218-231
[6] H. Chen, M. Ishida, T. Nakahara, "Influential Factors on Adhesion between Wheel and Rail under Wet Conditions", Railway Technical Research Institute, Tokyo, Japan; Tokyo Institute of Technology, Tokyo, Japan, 2011
[7] B. Allotta, E. Meli, A. Ridolfi, A. Rindi, "Development of an innovative wheel–rail contact model for the analysis of degraded adhesion in railway systems" Tribology International, Volume 69, January 2014, Pages 128-140
[8] http://www.xtriz.com/RootConflictAnalysisIntroduction.pdf
[9] http://www.apollorootcause.com/media/32309/realitycharting_-_seven_steps_to_effective_problem-solving_and_strategie....pdf
[9] Cooke, J., 2014, "Improving the value of products and processes by combining value analysis techniques and lean methods with TRIZ" TRIZ Future Conference 2014, Procedia CIRP
[10] Cooke, J., 2015, "TRIZ-based Modelling and Value Analysis of products as processes" TRIZ Future Conference 2015, Procedia CIRP
[11] A basic study of wheel/rail adhesion laboratory studies of the effects of Water – T.M. Beagley & C Pritchard, Tribology Section, Railway Technical Centre, 1973
[12] http://www.rssb.co.uk/Pages/research-catalogue/PB025427.aspx
[13] https://en.wikipedia.org/wiki/Track_circuit
[14] R. K. Taylor, The effectiveness of trackside water sprays on leaf affected track at Bearsted Bank 1979, Technical Memorandum TRIB 43, British Railways Board R&D Division.
[15] Victor Fey & Eugene Rivin, "Innovation on Demand, new product development using TRIZ" –ISBN 9780521826204, 2005, ARIZ Part 2, Pages 88-89
[16] http://www.ideationtriz.com/new/materials/finalconceptresources.pdf
[17] Y Sakamoto, T Kashiwagi, H Hasegawa, T Sasakawa, Y Karino, "Performance of Linear Motor Type Rail Brake Using Roller Rig Test Bench", Rail Technical Research Institute, QR of the RTRI, Volume 53, No.1, February 2012

What a well-trained TRIZ user can learn from other design methodologies: an initial speculation

Leonid Chechurin[a,*], Mika Lohtander[a], Yuri Borgianni[b]

[a]*Lappeenranta University of Technology, Skinnarilankatu 34, P.O. Box 20 FI-53851, 53851 Lappeenranta, Finland*
[b]*Free University of Bozen-Bolzano, Piazza Università – Universitätplatz, 5, 39100 Bolzano, Italy*

* Corresponding author. Tel.: +358504419193; *E-mail address:* leonid.chechurin@lut.fi

Abstract

A typical list of conceptual design tools in engineering consists of the following approaches: TRIZ, axiomatic design (AD), design for X, Robust Design and some others. The present paper focuses on two popular methods that include a rich theoretical background, i.e. TRIZ and AD, which are selected for a pilot experiment. They are normally treated as separate design techniques in the literature that recommends their integration only. To which extent can AD approach be seen as a particular case of the whole TRIZ body of knowledge and vice versa? The research question is to define the relationships between these methods, whether they overlap, which one is more general or specific and could be derived from another one. We provide comparative review on these methods to define their inputs, outputs and the rigidity of technique. Then, we discuss a set of classical AD-driven idea generation examples and approach them with the help of TRIZ. We discuss how AD axioms can be interpreted by TRIZ principles. We conclude that AD solutions can be viewed as particular cases of the whole body of TRIZ tools to support inventive design, but AD way of thinking results helpful to accelerate the design process. The results can be used to improve the design roadmap, to approach the general TRIZ-based concept design theory and a better logic of teaching. In addition, the paper proposes this kind of investigation for expanding this study, so to include different perspectives, other case studies and additional methodologies.

ISSN 1866-4180
Peer-review under responsibility of scientific committee of Triz Future Conference 2016.

Keywords: conceptual design; combination of design methodologies; TRIZ; Axiomatic Design; separation principles

1. Introduction

Within engineering design, various systematic tools are introduced to support the stage of conceptual design. At least two methods are considered as a fundamental for design education and research, namely TRIZ and Axiomatic Design (AD) [1]. They have been developed independently, which results in distinct communities of advocates and followers, distinct preferred journals, conferences and book chapters. To which extent are they different? What are the overlaps? Could any of the tools descend from the other and, if so, how could they contribute to an overall general approach to design?

In practice, engineers should be able to select the most suitable tool according to posed objectives. It is necessary to know which one seems to be the most general and, at the same time, to know in which specific situations the specific tool would provide the maximum benefit. With reference to the mentioned techniques, as it will be clarified in the followings, TRIZ supports the individuation of inventive technical solutions and AD is addressed at better articulating systems' design.

The present paper deals particularly with the benefits descending from other design methodologies in the eyes of a TRIZ user. The objective is pointing out which advantages can be gained by integrating AD and other techniques in a TRIZ-driven design process, according to authors' understanding, experience and preliminary tests. Therefore, the overall goal is supporting the decision of learning to master other tools, by taking into account estimated benefits and resources channeled to expand the knowledge of conceptual design techniques, which can result particularly onerous as clarified in [2, 3].

The paper is organized as follows. First, we provide a brief introduction on the methodologies and an overview on their integration, synergies and comparative studies. Further details can be obtained through the abundant literature about these topics.

Second, we compare TRIZ-driven and AD-driven design. We theorize how the principles of general TRIZ have a relationship with AD and which concepts of TRIZ overlap with AD-driven design evaluation. We illustrate these speculations by two case studies, a classical one (with respect to AD) and an original one.

Eventually, we conclude that, although TRIZ includes a large variety of conceptual design support tools (presumably the largest collection), some problems benefit from other methodologies largely. For instance, designers that master TRIZ can favorably learn AD fundaments if their typical problems regard the design and/or harmonization of complex systems.

2. Considered methodologies and studies of their interaction

2.1. TRIZ

TRIZ originates from the extensive study of patents and of their underlying inventive principles that has been performed by the theory's founder Altshuller in the former USSR [4]. The scientist found many affinities between the abstract patterns that led inventors to define their innovative solutions. After the identification of regularities in the development of inventive designs, the theory has evolved so to include systematic tools that support practitioners in technical problem solving. Actually, the theoretical development can be considered predominant with respect to the experimental verification and the diffusion of practices in industry. As a result, TRIZ has become a rich collection of design fundamentals beyond a powerful instrument for tackling conceptual design. A recent review points out the large number of domains in which said design knowledge is exploited [5].

However, in this paper, the authors focus on the capability of TRIZ to undertake the search for excellent designs in industrial problems and in product development initiatives. The remainder of the article includes the application of classical TRIZ tools, but no particular explanation of their underlying theory is presented, as these notions are taken for granted according to the expected readership.

2.2. Axiomatic Design

AD is a framework developed by Suh [6], which swivels on a couple of axioms (namely Independence and Information Axiom) that claim to describe the core elements of changing design representations. AD-based design procedures feature:

- The support of design thinking in terms of individuating relationships between and within systems, highlighting priorities and hierarchies, considering the changing nature and perspective of requirements from the definition of customer needs up to their final fulfilment in the production process;
- The elimination or reduction of dependencies between achievable functions and the design parameters that are seen as function carriers;
- The creation of flexible, adaptable and robust systems;
- The support in selecting design alternatives based on the greatest probability of obtaining the desired outcomes.

Within conceptual design, the Independence Axiom is particularly relevant, since it suggests simplifying the layout of the product or system. More in details, the axiom encourages the designer to avoid solutions in which more Design Parameters (DPs) are responsible for the fulfilment of one or more functions (or Functional Requirements, FRs, in AD jargon). This strategy is clearly a good starting point to avoid contradictions from a TRIZ viewpoint, but practical indications to achieve the expected outcomes are lacking in AD's body of knowledge and toolkit.

2.3. Designing with TRIZ and AD: advantages and limitations

The above brief description is sufficient to highlight how AD includes useful means for users of classical TRIZ. In particular, it seems to support a more formal description of the problem. Not surprisingly, [5], which analyses the most relevant TRIZ-based scientific sources, includes paragraphs that describe TRIZ juxtapositions to AD. In the wide variety of design methodologies that have been combined with TRIZ, AD has a prominent position. Besides, integration studies between TRIZ and AD are still ongoing, as discernable from recent literature [7].

With a historical perspective, the matching of TRIZ and AD is the core of numerous works and review papers. [8] can be considered the first large-scale study in which theoretical and methodological consonances between TRIZ and AD are underlined. The results obtained by case studies in which the two methods are combined is the thrust of [9], from which a new integration approach for the manufacturing field is proposed. However, despite positive results shown in literature and evident combination opportunities, articulated methodologies including TRIZ and AD have not really impacted on the industrial design practice. The reasons of this phenomenon are investigated in [10] and [11], by focusing on potential theoretical mismatches and orientation to different industrial domains, respectively.

The authors point out also specific solution-oriented limitations that result more apparent if other methodological integrations concerning TRIZ are taken into account.

Still with reference to the review works [2, 5], the integration of TRIZ with the set of Design for X methodologies is not infrequent. As Design for Manufacture and Assembly (DFMA) focuses on design simplification, this does not conflict with the general principle of ideality for TRIZ. The main contribution that juxtaposes TRIZ and DFMA [12] moves, besides, from the assumption that simpler systems give rise to cheaper manufacturing and assembly operations. A design objective to achieve this goal is the reduction of components belonging to products and systems under

development. This represents a relevant issue also in consideration of design for changeability [13], but can somehow conflict with AD's Independence Axiom. In each case and similarly for what happens with TRIZ-AD combination, most integration examples, e.g. [14], foresee that DFMA dictates design directions, while TRIZ is employed to identify the suitable solution thanks to its inventive capabilities.

The authors move from the above consideration. Several design methodologies can clearly complement TRIZ in terms of individuating objectives, structuring problems, tackling decisions, etc. However, it is questionable whether any technique can support TRIZ practitioners in terms of individuating inventive concepts that are suitable for the given case studies. By using AD as an illustrative well-acknowledged design technique for a pilot study, the methodological research questions the authors are facing follow:

- could AD lead to ideas that could not appear with TRIZ-driven invention procedures?
- which TRIZ tools should be applied in case the design process is articulated according to AD driving principles?

3. TRIZ in typical Axiomatic Design problems

3.1. Theoretical analysis

As already explained in the preceding part of the paper, the present contribution attempts to verify the utility of AD in supporting inventive activities of TRIZ users. In this field, the starting point is recalling the most remarkable open issues in the comparison and the combination of two of the strongest design theories. While the authors are particularly devoted to individuate overlaps, apparently diverging design objectives cannot be overlooked, as they could include diverse strategies to obtain good designs. According to literature, the main open questions can be summarized as follows:

- The procedures promoted by AD Independence Axiom, as highlighted above, lead to articulated designs that conflict with TRIZ Law of Ideality Increase [15] and partially with the second axiom [13], whose popularity and practical use is however much lower [16];
- The uncoupling between DPs and FRs, still suggested by the Independence Axiom, encompasses a broader spectrum of problems with respect to cases in which a contradiction (in TRIZ terms) is present and has to be overcome [10];
- AD allows to work with an articulated set of parameters and functions, while TRIZ is suitable for problems in which a "trivial" contradiction is pointed out [11].

The last issue is not particularly relevant to the scopes of the paper, also because good outcomes can emerge if designers analyze all possible conflicting pairs and eliminate the extant contradictions. The first two questions are somehow correlated and constitute the main aspects that should be clarified; more details follow.

The correct and integral application of the Independence Axiom leads, where possible, to the definition of systems in which a unique function carrier provides for the fulfilment of a desired output. This condition implies that the numbers of DPs and FRs are equal. At the same time, this circumstance ensures the absence of contradictions, as no parameter influences the delivery of two or more functions contextually. We can deduce that a similar result can be achieved by a separation procedure, but it is unclear whether TRIZ separation principles are sufficient and enough flexible to face the challenges posed by the Independence Axiom. It has to be remarked that, according to the second point of the above bullet list, the situations featured by AD couplings and TRIZ contradictions may not necessarily coincide, although an independent authors' search for practical cases in which the two concepts collide has not resulted in large numbers of industrial examples.

Authors' approach to two case studies supposedly provides a contribution in terms of clarifying the situation, but it cannot be considered exhaustive to tackle the issue. In the former, the most common example to elucidate AD principles is exploited; an application of classical TRIZ problem solving procedure is applied. The same kind of simulation concerns the latter, which reports a real problem that the authors have tackled with AD quite effortlessly.

3.2. Example 1. Faucet design analysis

As introduced in the previous paragraph, the authors attempt to face the classical problem described by AD handbooks, i.e. the faucet problem, by means of TRIZ tools and markedly through separation principles. Indeed, we have already highlighted that separating is viable to result the most outstanding TRIZ tool, capable of complying with the objectives of the Independence Axiom.

Situation: the faucet has to allow the supply of water at a desired temperature and flow rate.

AD suggests that the traditional design of the faucet generated regulation problems, as the flow rates of hot and cold water influenced both the global flow rate of water and its temperature (see Fig. 1). The problem can be overcome by assigning two distinct separate function carriers the desired outcomes. Thanks to the mixer faucet (see Fig. 2), two different regulation angles, i.e. left vs. right and bottom vs. top, are responsible for the temperature and the flow rate of the water, respectively.

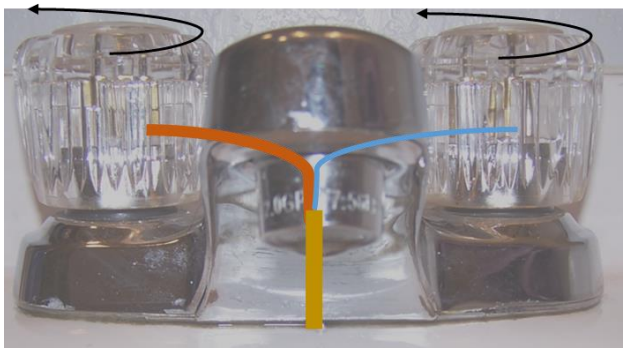


Fig. 1. Traditional design of a faucet, in which both hot and cold water are delivered in order to obtain the desired amount and temperature of water

Fig. 2. Design of a mixer faucet, in which two different regulations are responsible for the desired amount and temperature of water

The authors tried to achieve the same result by systematically implementing the most indicated TRIZ tools, starting from the initial faucet design.

Initial problem formulation: One needs to achieve the desired temperature and flow rate of the water, which can be obtained by rotating left and right faucets. At this stage of analysis, no contradiction.

Reformulation: However, it is unpractical to obtain the target values, because both faucet openings influence both temperature and flow rate. If the water is too cold, I have to put more hot liquid in the circuit, but this destabilizes the quantity of flowing water. Hence, I have to reduce the quantity of both hot and cold water proportionally, but, in general, the process results in multiple adjustment iterations. There is a control problem of the technical system. In these terms, I want to increase (modify) the angle associated with the hot water, in order to change the temperature, but, at the same time, I do not want to change it, in order to keep the water flow rate. We are facing a physical contradiction, which can be therefore addressed with separation principles.

Formal definition of the contradiction: the control parameter is the angle of the left faucet in the traditional design. It has to assume two different values at the same time in order to fulfil the desired outcomes, i.e. the correct temperature and flow rate of water (thus, the two evaluation parameters). The definition of the operating space and time is not straightforward.

Separation in time: I want to achieve the desired flow rate and temperature contextually. No solution has been individuated.

Separation in space: the separation strategy suggests providing hot water to warm up the water ending in the sink, but not mixing with it, so as not to increase the flow rate. In a certain sense, a function carrier for the temperature is required, other than the ones we have for the flow rate. This could emerge by making the reasoning fit in with the final outcome, but it clearly does not result by a systematic and linear application of TRIZ tools.

Separation in conditions: In this case, it seems pointless to use this separation procedure.

Separation macro-micro: Do I need the temperature of the water globally with a certain value and locally with another one? Maybe, when I am washing my hands, I need warm water to feel comfortable and kill bacteria, the flow is associated with the necessity of removing soap and feeling refreshed by a sufficient amount of water. But this does not lead to any solution systematically, beyond the fact that this is not always the case, e.g. when I have to fill the bathtub, I want a specific temperature and a good flow rate to end the process quickly.

Other TRIZ tools: The Inventive Principle of dynamics, if applied to the faucet, could lead towards the known solution that AD spotlights. Once again, this result seems more an attempt to justify the use of TRIZ heuristics, rather than the systematic application of Altshuller's theory. Similarly, some Trends of Engineering Systems Evolution seem compliant with the mixer faucet: more systems are integrated into a single solution that supplies both hot and cold water (and a mixture as well). At the same time, the solution of the mixer faucet is compliant with TRIZ ideality, at least in terms of minimizing the use of components and material. This conflicts, at least partially, with the above discussed dichotomy between TRIZ ideality and AD independence.

Comparison: The authors have already stated that an independent design according to AD is a design where a contradiction has been resolved. The solution of the mixer faucet can represent an elegant case in point. AD points out how this successful product architecture supports the Independence Axiom, but it is questionable to affirm whether the need of separating the function carriers would itself lead to the technical solution. Despite the large and structured body of knowledge that TRIZ possesses, a systematic employment of TRIZ techniques did not clearly bring to the expected outcome. In this specific case, the contradiction did not emerge clearly and, at the same time, issues to address the separation of function carriers seem to lack. Obviously, other scholars and practitioners could argue these specific outcomes, as the results of the problem solving task clearly depend on designers' capabilities too.

3.3. Example 2. Split system montage design

Situation: Any air-conditioning indoor block has to be mounted on a wall. The installation process is supposed to include the following steps:

- The installation plate is mounted on the wall. Special attention is given to maintain a perfectly horizontal position of the plate's holding hooks to ensure the proper placing of the block (see Fig. 3);
- The block is hanged on the hooks.

Although the process does not seem to be particularly complex, the horizontal positioning of the plate takes some time. Moreover, the reality of the installation process reveals additional controlling measurements. First, the horizontality of the installation plate's holes is checked. Second, having installed the plate on its position, the operator checks if the plate's hooks are horizontal. The third horizontality check takes places after the block is placed on the hooks and connected to the gas supply pipe and electricity. This happens because the hook not always finds its slot completely or because the gas supply pipe can impose some vertical force on the block's edge.

AD-driven design process: We can start AD application

only when DPs and FRs have been defined. Moreover, the number of DPs is preferably equal to the quantity of FRs in order to approach the design by AD axioms in a more effective way. Let us assume what follows:

- DP1: Fixing point one (hole/hook 1);
- DP2: Fixing point two (hole/hook 2);
- FR1: Hold the (weight of the) block;
- FR2: (make it easy to adjust and then) to maintain the horizontal position.

Fig. 3. Traditional design concept to hold the block of an air-conditioner

The design seems to be "natural" and simple. Both fixing points are symmetric, as well as they have to assume the same height from the floor. DP1 and DP2 are thus the height of both the hooks or, likewise, of both the holes. In this scheme, the matrix is coupled and this does not represent a good design in an AD perspective. Indeed, according to AD's first axiom, the matrix has to be uncoupled (diagonal). In order to support the above statement of the coupling condition, it is sufficient to point out that the correct positioning of holes and hooks (DP1 and DP2) participate in maintaining the horizontal position (FR2), beyond contributing to support the air-conditioning system (FR1).

Once the problem is formulated in this way and indications from independence axiom are assumed, it is easier to come to another concept of the block-fixing mechanism. One fixing point has to be on the vertical center axis (more precisely, on the vertical line crossing the barycenter of the block). This fixing point has to be strong enough to hold the weight of the block. Another fixing point has to maintain the torque with respect to the axis defined by fixing point 1. Thus, the fixing point 2 has to be placed near the side edge of the block. The decomposition of the functions expressed through the FRs requires a completely different design (Fig. 4).

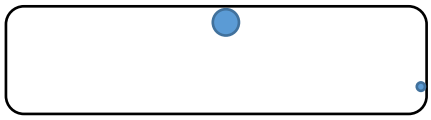


Fig. 4. AD-inspired block fixing design that foresees the fulfilment of Independence Axiom

More specifically, the first fixing point has to be strong and stable as far as the vertical displacement of the center of gravity is considered, while indifferent against possible block's rotation. DP2 is not responsible for holding the weight of the block, but it defines its rotation around the point determined by DP1. The new design requires little inventiveness, as the hook that must provide for the block holding can be a standard item, although more resistant than those normally employed. In order to design the hook correspondent to the DP2, we should enable easy correction of block's angle, so as to adjust and maintain its horizontal position. For example, a kind of ratchet as in Fig. 5 could be suitable to the scope.

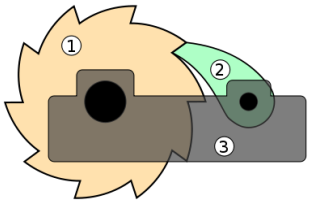


Fig. 5. Example of a ratchet proposed to fulfil the FR2; image from Wikipedia page concerning "Ratchet (device)", which includes major information about the apparatus and the components illustrated in the picture

TRIZ-driven design analysis: First, we need to start from exactly the same point to be able to compare AD- and TRIZ-driven design. Thus, we assume that the starting point for the analysis is given in Fig. 3. In other words, we have to consider the same conditions dictated by the recalled DPs and FRs.

Contradiction analysis: The FRs are not independent in the design depicted in Fig. 3. Moreover, the better we ensure FR1 (fixing the block to hold the weight), the worse FR2 (our ability to control the block angle) is fulfilled. In other words, the mentioned DPs contain the physical contradiction. The fixing points have to be strong (to hold the mass) and at the same time loose (to adjust the angle).

Alternatively, it is easy to place two hooks somewhere and hang the block (FR1 is ensured), but it is impossible to adjust the angle of the block with respect to the horizontal line (FR2) afterwards. The more time we spend on the precise positioning of the two hooks, the better the FR2. This formulation recalls an engineering contradiction.

Both contradiction models elucidate that there is something wrong in the design of Fig.3 and suggest eliminating the contradictions to generate new and better performing ideas. For example, separation principles suggest changing the DPs in such a way that FRs are not contradicting anymore. Thus, a good design would foresee a new situation where holding (the weight of the block) is separated from changing the angle of the block. It addresses a separation in conditions principle. Alternatively, the designer can be inspired by separation in time principle. We can model the design in which the block is always held tightly, with the exception of the time in which the operator adjusts its angle. Both separation principles cover the idea depicted in Figs. 4 and 5. To this point, it is worth remarking that time is never a player in AD, as well as Suh's design theory displays limitations with regard to time-dependent problems [17]. We can hypothesize (but this does not represent the thrust of the paper, nor any demonstration will be provided), that separation in time can result a fundamental aid in those cases that feature failures in the application of the Independence Axiom.

Trends of engineering system evolution: The trend of dynamicity increase points out that evolution of any engineering system is described by a transformation from its rigid version to an adaptive one and from the latter to a self-adaptive one. The fixing system design in Fig 3 is simple but, at the same time, non-adaptive. The trend indicates that there is space for design improvements and shows a way for achieving enhancements: for instance, to consider making the design more flexible and adaptive. The idea of the design in Figs 4 and 5 undoubtedly shows more flexibility and adaptability (the angle can be adapted).

Ideality: The concept of ideality or ideal final result in TRIZ is very generic in its formulation. For example, with respect to

the design in Fig 3, it could help to model an "ideal" installation process. In such a model process, there are two steps only: (1) the block is hanged on its place and (2) its angle is corrected (ideally, by itself). The process of installation of Fig. 3 seems to be not ideal in this perspective.

Comparison: Both AD and TRIZ can be used to evaluate the design and to find what can be improved. TRIZ-driven analysis is capable of detecting the same disadvantages highlighted by Axiom 1's failure.

AD requires that FRs and DPs are defined and the quantity of FRs and DPs has to be equal. It substantially limits the variety of solutions dictated by the method. Conversely, TRIZ tends to conceive designs in which a large number of FRs are ensured by a limited quantity of DPs, or at least the number of components should be minimized.

4. Conclusions

The present paper has illustrated a pragmatic approach to individuate whether other methodologies can support TRIZ practitioners in the inventive phase of design. AD has been adopted as a sample method that is often juxtaposed to and/or compared with TRIZ in literature; hence, it has been exploited for a pilot study. The initial scope of this activity is not providing a final answer to the proposed research questions, but delineating some issues emerged from authors' experience and promoting a wider debate.

Initial outcomes show that the solutions inspired by Suh's theory and axioms can be achieved also through TRIZ employment. Besides, AD tends to restrict the solution space by posing constraints on the number of function carriers and avoiding the definition of dynamic systems. However, some limitations to what is stated have to be claimed:

- The procedure to obtain solutions with TRIZ is not always clear and straightforward, thus the structuring of the problem in AD terms can support the designer in speeding up the process; we have to point out that both the problems faced in Section 3 deal with adjustment and regulation issues, which can somehow represent a domain in which TRIZ is not the most effective;
- Although separation principles can be seen as the best option to fulfil the indications of the first AD axiom, these tools do not necessarily lead to the same solutions. It is well known that the rich collection of TRIZ solving principles can lead to diversified concepts; in this sense, the individuation of the most suitable tools to address typical AD problems (i.e. the so-called coupled designs) should be better investigated.

The above findings confirm to some extent hypotheses based on literature and on logical considerations about the nature of the two theories and methodologies. However, some considerations could not be derived without a simulated employment of TRIZ in problems already faced by means of AD. This makes the authors suppose that this experimental approach can result useful in getting a greater understanding about limitations of TRIZ in the design practice and potential support from other techniques and ways of thinking with obvious repercussions in the field of design education. In consideration of the presented results, the authors urge other scholars and practitioners to expand these results through similar experiments performed by other fellows, new case studies and design methods. This could be done independently or through a cooperation with the authors by contacting the corresponding author. In the meantime, the authors are planning the adoption of the proposed investigation strategy by comparing TRIZ results in examples supported through DFMA.

Acknowledgements

L. Chechurin and M. Lohtander would like to acknowledge TEKES, the Finnish funding agency for innovation and its Finnish Distinguished Professor (FiDiPro) program that supported the research.

References

[1] Tomiyama T, Gu P, Jin Y, Lutters D, Kind C, Kimura F. Design methodologies: Industrial and educational applications. CIRP Annals-Manufacturing Technology 2009;58:543-65.
[2] Hua Z, Yang J, Coulibaly S, Zhang B. Integration TRIZ with problem-solving tools: a literature review from 1995 to 2006. International Journal of Business Innovation and Research 2006;1:111-28.
[3] Becattini N, Borgianni Y, Cascini G, Rotini F. Computer-aided problem solving - Part 2: A dialogue-based system to support the analysis of inventive problems. IFIP Advances in Information and Communication Technology 2012; 355 AICT:132-148.
[4] Altshuller GS. Creativity as an exact science. Amsterdam: Gordon and Breach Science Publishers; 1984.
[5] Chechurin L, Borgianni Y, Understanding TRIZ through the review of top cited publications. Computers in Industry 2016;82:119-34.
[6] Suh N. The principles of design. New York: Oxford University Press; 1990.
[7] Ko YT. Modeling a hybrid-compact design matrix for new product innovation. Computers & Industrial Engineering 2016, in press.
[8] Kim YS, Cochran DS. Reviewing TRIZ from the perspective of axiomatic design. Journal of Engineering Design 2000;11:79-94.
[9] Shirwaiker RA, Okudan GE. Triz and axiomatic design: a review of case-studies and a proposed synergistic use. Journal of Intelligent Manufacturing 2008;19:33-47.
[10] Borgianni Y, Matt DT. Axiomatic Design and TRIZ: Deficiencies of their Integrated Use and Future Opportunities. Procedia CIRP 2015;34:1-6.
[11] Borgianni Y, Matt DT. Applications of TRIZ and Axiomatic Design: A comparison to deduce best practices in industry. Procedia CIRP 2016;39:91-96.
[12] Bariani PF, Berti GA, Lucchetta G. A combined DFMA and TRIZ approach to the simplification of product structure. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 2004;218:1023-7.
[13] Fricke E, Schulz AP. Design for changeability (DfC): Principles to enable changes in systems throughout their entire lifecycle. Systems Engineering 2005;8:342-59.
[14] Aslian A, Razak ABA. Invention through integration of TRIZ and DFMA methodologies. International Journal of Mechanical and Production Engineering Research and Development 2013;3:149-54.
[15] Mann D. Axiomatic design and TRIZ: compatibilities and contradictions. Proceedings of ICAD2002 - Second International Conference on Axiomatic Design 2002.
[16] Kulak O, Cebi S, Kahraman C. Application of axiomatic design principles: A literature review. Expert Systems with Applications 2010;37:6705-17.
[17] Lu SCY, Suh NP. Complexity in design of technical systems. CIRP Annals-Manufacturing Technology 2009;58:157-60.