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# THE 14TH INTERNATIONAL CONFERENCE

## TRIZfest - 2018

September 13-15, 2018, Lisbon, Portugal

### CONFERENCE PROCEEDINGS

*Editor: Oliver Mayer*



*Local Organizer:*



FACULDADE DE  
CIÊNCIAS E TECNOLOGIA  
UNIVERSIDADE NOVA DE LISBOA

## **Proceedings of the 14th MATRIZ TRIZfest-2018 International Conference**

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Conference is intended for TRIZ specialists and users: academics, engineers, inventors, innovation professionals, and teachers.

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

All presented papers are double blind peer-reviewed.

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Dear colleagues!

It is my honor to welcome the participants and guests of the TRIZfest-2018 conference. The conference has become a good tradition and allows us to get familiar with the latest achievements of the TRIZ community.

We have gathered here on the beautiful coast of the Atlantic Ocean to discuss the actual problems of improving and disseminating the modern Theory of Inventive Problem Solving. We are not simply colleagues, but rather one big TRIZ family. The business atmosphere of the conference will help us to meet new friends and will support the uniform understanding and using the most effective tool for improving every kind of system.

The conference program is extensive. It presents reports on many areas. We will be able to get acquainted with the results of studies carried out by our colleagues, with the experience of practical use of the TRIZ and VEA techniques, learn about the achievements of TRIZ pedagogy and other TRIZ applications. You can take part in the discussions and express your point of view on the topics of the presentations. This, undoubtedly, will give the authors an opportunity to improve the works presented by them.

It should be noted the high quality of the papers in the proceedings of the conference. This became possible due to the high qualification and hard work of the members of the Program Committee, organized by the Papers Review Chair, TRIZ Master, Dr. Oliver Mayer.

I appreciate the high level of organization of the conference. For this we must express our gratitude to Conference Co-Chairs TRIZ Master Dr. Mark Barkan (MATRIZ) and Prof. V. Cruz Machado (Universidade NOVA), as well as the General conference coordinator Prof. Helena Navas (Universidade NOVA). We have the opportunity to get together due to the efforts of these people and their team.

I am sure that the ideas of the development of TRIZ and VEA presented at the conference will be in demand in your professional work. The results of the conference will contribute to the achievement of modern quality of real works on the improvement of technical and other complex systems. I am confident that our future cooperation in the framework of MATRIZ will be as fruitful and successful as the future! I wish all the participants and guests of the conference successful and fruitful work!

MATRIZ President

Dr. Yury Fedosov, TRIZ Master



A handwritten signature in black ink, reading "Y. Fedosov". The signature is stylized with a large, looped 'Y' and a cursive 'Fedosov'.



TRIZ, the “Theory of Inventive Problem Solving” is a living science and a practical methodology. In the last decades, research has proceeded in several stages. We are assisting to a growing interest on TRIZ especially within the industrial context. Large and small companies worldwide are using TRIZ at many levels to solve problems and to develop strategies for future technologies and products.

The 14th International Conference TRIZfest-2018 is organized by the International TRIZ Association (MATRIZ) in partnership with Faculty of Sciences and Technology, Universidade NOVA de Lisboa.

TRIZfest-2018 is the fourteenth international gathering of scientists and senior officials of companies interested in the topic of TRIZ Methodology and Innovation and its applications, scheduled for September 13-15, 2018 in Lisbon, Portugal. The last conference of this series was held in Krakow (Poland, in 2017). These International Conferences TRIZfest resulted from the belief that associated with TRIZ and innovation techniques have been making continuous and significant advances during the years. Important and dramatic improvements in systems and component design can be made by the use of the latest advances in Systematic Innovation.

The Conference aims at creating a forum to enable the interchange of research, practice, know-how and experience between industrial companies, research centers, educational organizations, academic institutions, and individuals on systematic innovation. Also we would like to leave words of acknowledgment for the members of the Scientific and the Technical Committees, the Secretariat and all those who contributed to the success of the Conference.

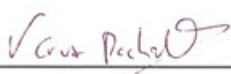
The organizers of the International Conference TRIZfest-2018 are pleased to present the proceedings of the conference. Author and non-author participants from different countries will interact in the conference.

Whether the papers included in the proceedings are work-in-progress or finished products, the conference and proceedings offer the authors an opportunity to disseminate the results of their research and receive early feedback from colleagues, without the long waiting associated with publication in peer-reviewed journals. On the other hand, the presentations and the proceedings do not preclude the option of submitting the work in an extended and finished form for publication in any peer-reviewed journal. The organizers are indebted to a number of people who gave their time to make the conference a reality. The list of organizations and working team who have contributed tremendous amount of time and efforts to create this conference are acknowledged at the end of this program brochure. There are more contributors who are beyond the list.

We are confident that you will find the participation in this conference rewarding. If there is anything needing assistance, please feel free to let the attendant(s) at the service desk know. We are here to serve you.

Conference Co-Chair, Dean of the Faculty of Sciences and Technology,  
Universidade NOVA de Lisboa, Portugal



  
\_\_\_\_\_  
**Prof. Virgílio Cruz Machado**

Dear TRIZfest-2018 Participants and Readers of the Proceedings,  
TRIZfest could not happen if there was no agility in the community to apply, use and further develop the TRIZ methodology. The papers that were presented in the past and today at TRIZfest-2018 at the conference are a prove of the actuality and the ability to move forward with this great tool and mind set.

Just like in the past years, it took some efforts to prepare this conference. Valeri Soukhov set a benchmark in the past for the compilation of the proceedings and I am proud that he forwarded this important job for 2018 into my hands. The Paper Review Committee and Board worked hard to select best papers to be presented at the event in Lisbon.

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

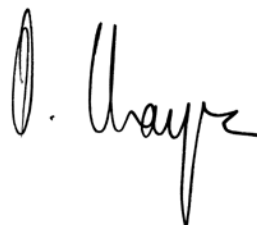
- TRIZ research, methodology, development.
- Development of competence with TRIZ.
- Integration of TRIZ with other methods and tools to enhance systematic innovation.
- Sharing experiences with best practices of using and implementing TRIZ.
- Case studies with the use of TRIZ

We would like to thank all the authors and co-authors who shared their work and experience with the community to allow these proceedings to be compiled. The continuous flow of abstracts and papers over the years shows as well the considerable impact on further development of TRIZ and its dissemination around the world.

We would like to express our sincere gratitude to all the members of the TRIZfest-2018 Organizing Committee who provided their help and support as well as to the members of the Papers Review Committee who invested their precious time to select the best papers and provide authors with comments how to improve their papers. Especially I would like to share credits to J. Patrick Roxas for his continuous engagement in supporting the proceeding compilation.

Please enjoy reading of the multiple new approached in the TRIZ world.

Dr. Oliver Mayer, TRIZ Master  
Chair of the TRIZfest-2018 Papers Committee  
Munich, Germany

A handwritten signature in black ink, which appears to read 'O. Mayer'.

## TABLE OF CONTENTS

<b>Welcome Addresses</b>	<b>4</b>
<b>TRIZ and Software Evolution</b>	<b>9</b>
<i>Luiz Carlos Guedes (Instituto Militar de Engenharia, Brazil)</i>	
<b>TRIZ Modelling of X-Ray Phase Contrast System for Medical Applications</b>	<b>19</b>
<i>Tiziana Bertoncelli, Oliver Mayer (GE Global Research, Germany) Cristina Cozzini, Guido Kudielka (GE Healthcare, Germany)</i>	
<b>Indicating System Vulnerabilities Within Ceca Model</b>	<b>31</b>
<i>Jerzy Chrzyszcz (Institute of Computer Science, Warsaw University of Technology, Pentacomp Systemy Informatyczne S.A, Poland)</i>	
<b>Application of TRIZ Methods for Alternatives in Cardiac Activity Detection in Magnetic Resonance Imaging</b>	<b>38</b>
<i>Guido Kudielka (GE Healthcare, German) Tiziana Bertoncelli, Oliver Mayer (GE Global Research, Germany)</i>	
<b>Identification and Utilization of the Most Efficient Resources Among Those Available</b>	<b>49</b>
<i>Oleg Feygenso (Samsung Electronics, South Korea), Naum Feygenson (En+ Group, Russia)</i>	
<b>Identifying Key Problems and Conceptual Directions: Using the Analytical Tools of Modern Triz</b>	<b>55</b>
<i>Oleg Y. Abramov (Algorithm Ltd., Russia) Stéphane Savelli (MP Solving, Belgium)</i>	
<b>Paradigming TRIZ as Design Frames in Philosophy Education</b>	<b>69</b>
<i>Ruud Heesen (Varendonck College, The Netherlands), Christoph Dobrusskin (Royal Philips, The Netherlands)</i>	
<b>Identifying Key Problems and Conceptual Directions Using the Analytical Tools of Modern Triz</b>	<b>82</b>
<i>Vinodh Mewani (Global Patents Operation, GE Global Operations, India), G. Nagashiresha (Advanced Technologies, GE Aviation, India)</i>	
<b>Contact Lens Technology Evolution - A Study of Correlation Between Patents and Triz Trends</b>	<b>93</b>
<i>Indrajit Pande and Vinodh Mewani (Global Patent Operations, General Electric Company, India)</i>	
<b>Innovation Funnel of Modern Triz: Experimental Study to Show the Efficacy of the Triz-Assisted Stage-Gate Process</b>	<b>105</b>
<i>Oleg Y. Abramo<sup>a</sup>, Sergey A. Markoso<sup>a</sup>, Alexander V. Medvedev, Vladimir Y. Rychagov (Algorithm Ltd., Russia)</i>	
<b>Su-field Analysis in Optics: Research and Practice</b>	<b>111</b>
<i>Pavel Fimin and Vladimir Rychagov (Algorithm Ltd., Russia)</i>	

<b>The Integration of Triz Methods With Eco-design and Lean Design: A Literature Review and Future Research Directions to the Development of a New Model</b>	<b>123</b>
<i>Claudia Muiambo (Instituto Superior de Engenharia de Lisboa, Portugal), Isabel M. João (Instituto Superior de Engenharia de Lisboa, Instituto Superior Técnico, Universidade de Lisboa Portugal) Helena Navas (Universidade NOVA de Lisboa, Portugal)</i>	
<b>The Fast Diagram for Triz</b>	<b>136</b>
<i>Kai Hiltmann (Coburg University of Applied Science, Germany)</i>	
<b>TRIZ Approach to Internet of Things</b>	<b>148</b>
<i>Simon Litvin (GEN TRIZ, USA), Andrey Prokofiev (Algorithm Ltd., Russia)</i>	
<b>Selecting and Validating Key Problems in Triz Projects</b>	<b>158</b>
<i>Arthur Lok (Innovation Empowerment Center, China)</i>	
<b>Triz in Schoolproject Sensus</b>	<b>170</b>
<i>Annemieke Vermeijlen (Van Maerlantlyceum, The Netherlands) Christoph Dobrusskin (Philips Innovation Services, The Netherlands, Hans Baaijens (Eindhoven, The Netherlands) Annemieke Vennix (Heerbeek College, The Netherlands), Carla Upperman (Frits Philips Lyceum, The Netherlands) Maritza Rovers (SensUs Organization, Eindhoven University of Technology, The Netherlands)</i>	
<b>Taking Human Factor Out of Equation. A Technical Remedy for a Managerial Challenge</b>	<b>176</b>
<i>Sergey Faer, TRIZ Master, Mark Barkan, TRIZ Master</i>	
<b>Method of Paradoxes For Those Who Have Mastered the Basic Concepts of Classical Triz: Ideality, IFRs, Resources, Contradictions.</b>	<b>181</b>
<i>Sergey Faer, TRIZ Master, Mark Barkan, TRIZ Master</i>	
<b>Automating Triz for Crowdsourcing Applications</b>	<b>196</b>
<i>Aleksei Ruin (Belgium) and Andrii Konovalenko (Ukraine)</i>	
<b>Study of Evolution Patterns of Display and TSP Technology</b>	<b>204</b>
<i>Minuk Kim, Harksang Kim, Chang-Ryong Heo (Telecommunication Business Division, Samsung Electronics, South Korea), Mijeong Song, Kunwoo Baek, , Hyeongsuk Yeo (Global Technology Center, Samsung Electronics, South Korea), Kyuhyun Cho (Medical Device Division, Samsung Electronics, South Korea)</i>	
<b>Triz&amp;Toc Tool Innovation: Vibration Sensory (Vs) Language for Deaf</b>	<b>213</b>
<i>José Roberto Espinoza Villarroel (Open TRIZ Second Wave Chile SpA, Chile)</i>	
<b>Contradictions of User Interface (UI)</b>	<b>234</b>
<i>Valeriy Prushinskiy (Samsung Electronics, South Korea)</i>	
<b>A Theoretical Model and Roadmap for Applying Triz in an R&amp;D Organization</b>	<b>247</b>
<i>Arthur Lok (Innovation Empowerment Center, China)</i>	

<b>Research on Seismic Structure of High Pier Railway Bridge Based on TRIZ</b>	<b>255</b>
<i>Hu Lianjun, Yang Jizhong, Wei Yongxing, Zheng Xiaoyan, Yuan Zhigang (China Railway Eryuan Engineering Group Co. Ltd., China)</i>	
<b>Design for Innovative Hydraulic Valve Structure Based on Triz and Multi-element Coupled Biomimetic Method</b>	<b>264</b>
<i>Zitong Zhao, He Xu, Haihang Wang, Liye Jiao, Vishwanath Pooneeth (College of Mechanical and Electrical Engineering, Harbin Engineering University, China)</i>	
<b>Design of Flexible Arm Based on Biotriz and Multi-Factor Coupled Bionic Technology</b>	<b>274</b>
<i>Xueshan Zhou, He Xu, Peng Li, Wanda Zhao, Kundan Sharma, Haihang Wang (College of Mechanical and Electrical Engineering, Harbin Engineering University, China)</i>	
<b>Feedback to Intermediate Steps in Practical Substance-Field Generation</b>	<b>284</b>
<i>Michael Schöwel (Germany)</i>	
<b>Trends of Engineering System Evolution in Toy/Kids Industry</b>	<b>290</b>
<i>Jerzy Obojski (Novismo, Poland)</i>	
<b>Research on Cultivation Mode of Consultants in TRIZ Methodology</b>	<b>302</b>
<i>Alp Lin (China)</i>	
<b>The TRIZ Introduction at the Enterprises of the Group of Companies Basic Element</b>	<b>310</b>
<i>Sergey A. Yakovenko (Moscow State University, Faculty of Physics, TRIZ Departments of RUSAL, BasEL, En+, Moscow), Alexander V. Kudryavtsev, Viktor E. Minaker, Elena V. Redkolis, Andrey A. Tarasov, Naum B. Feygenson, Mikhail S. Rubin, Nikolay E. Saunin, Yuriy N. Litvak, Andrey B. Rozhnov, Boris I. Tkachev, Alexey Y. Fomenko, Oleg M. Gerasimov, Yuriy V. Lebedev, Sergey A. Logvinov, Sergey A. Kondrat, Nikolay A. Schedrin, Vladimir N. Nikitin, Evgeniy V. Panchikhin, Mikhail A. Scherbakov, Oleg A. Kraev (TRIZ Departments of RUSAL, BasEL, En+, Moscow)</i>	

# **TRIZfest 2017 Main Sessions**



# **TRIZfest 2018**

## **September 13-15, 2018. Lisbon, Portugal**

### **TRIZ AND SOFTWARE EVOLUTION**

Luiz Carlos Guedes<sup>a</sup>

<sup>a</sup>*IME - Instituto Militar de Engenharia, Rio de Janeiro, 22290-270, Brazil*

#### **Abstract**

Software community has always been very skeptical regarding using TRIZ for software development. They might indeed have a point because, besides TRIZ for software be on its very childhood, TRIZ was not conceived with information systems in mind. Moreover, it seems that TRIZ application on software development has been targeted to solve problems that are not on the radar of software developers during software creation. As software complexity increases with computer capacity, current software development methodologies target an ideal software result and focus their attention on processes to manage the complexities related to resource allocation. Therefore, at the development phase of the software lifecycle, usually, there are no contradictions that could benefit from TRIZ to be solved. On the other hand, once a software is running, there are very few or no methods to guide on how to evolve it systematically. On this paper, we propose an approach to apply TRIZ's Trends of Evolution to guide the software developer to evolve their systems. We also present the case of a real software system that has evolved accordingly and to which the evolution roadmap has been planned after the approach proposed here.

Keywords: TRIZ, Software, Trends of Evolution, Software Evolution, POSWEB.

#### **1. Introduction**

In spite of some effort made in the past to apply a broader set of TRIZ tools to Software problems [1] or to structured programming[2], most of the effort on applying TRIZ for software is related to mapping the 40 Inventive Principles to Software [3][4][5][6][7][8]. Interestingly not much effort has been made on finding which Inventive Principles should be applied on a particular problem or even on generic problems. Outside Darrell Mann's Contradiction Matrix for Software [9] there are very few works published on the theme, notably [10] that uses TRIZ for Software architecture and suggests that Software quality attributes could be mapped to the technical parameters of the Contradiction Matrix.

Beckmann [11] proposes an interesting approach to mapping the Inventive Principles on to the Software domain. Beckmann claims that TRIZ Inventive Principles should provide solution models for three independent characteristics of information technology system, namely Objects (devices), Data and Algorithms (code). Disregarding how he maps the Inventive Principles to software solution models, these three characteristics can be viewed as dimensions under which every principle can be interpreted and should provide solution models for information technology (IT) systems.

Under the author point of view, this split into three dimensions is the missing link between TRIZ Inventive Principles and IT Systems. Before that, thinking about the mapping of Inventive Principles to IT systems, lead to results that did not seem to belong to the same realm. For instance, Inventive Principle #1 – Segmentation. It is easy to imagine that a large storage device (object) could be split into a Redundant Array of Indexed Disks – RAID, but also that some data could be split into a table of records or a program (code) split into modules. Although, all of these three so-

lutions are valid applications of the Segmentation principle to the realm of software, they look so unrelated that they do not look like valid suggestions to solve the same problem. And indeed, they are not.

As there is no solid strategy to select Inventive Principles neither a common understanding of their interpretation for software, we propose here to use TRIZ to evolve software systems using the Trends of Evolution combined with the Beckmann's three dimensions of IT systems.

## 2. Trends of Evolution

Although originally published by Altshuller [12] as "Laws of System Development" when moved to the west, the term 'laws' was changed to 'trends' or 'patterns' in order to fit to cultural expectations, becoming mostly known as "Trends of Evolution". Despite of the name adopted, we have classified them in two groups. The first one is made of the trends that are used to check whether your system is evolving on a promising direction or if there is something preventing it from evolving. These are called here Checking Trends. The second group is made of the trends that suggest you how to act on your system in order to evolve it. These are called here Acting Trends. Therefore, using the names chosen at [13][14], we divide them into:

Checking Trends of Evolution:

- Increased Ideality
- S-Curve Stages Evolution
- Non-Uniform Evolution of Parts

Acting Trends of Evolution:

- Increasing Segmentation
- Increasing Dynamism and Controllability
- Simplicity-Complexity-Simplicity
- Matching and Mismatching
- Less Human involvement

Curiously, the, here stated, Acting Trends are somehow related to Inventive Principles, while the Checking Trends are not. Digging into this relation is out of the scope of this work but it deserves some attention on the future. This relation is very convenient, considering that, like Inventive Principles, Acting Trends of Evolution are supposed to be applied to a system in order to obtain a better (evolved) version of it.

- |   |  |
|---|--|
| • Increasing Segmentation                 | → Inventive Principle #1 – Segmentation  |
| • Increasing Dynamism and Controllability | → Inventive Principle #15 – Dynamism     |
| • Simplicity-Complexity-Simplicity        | → Inventive Principle #5 – Merging       |
| • Matching and Mismatching                | → Inventive Principle #4 – Asymmetry     |
| • Less Human involvement                  | → Inventive Principle #25 – Self-service |

## 3. Dimensions of IT Systems

According to Beckmann [11], the abstraction of physics that Information Technology (IT) provides to system developers allows them to model their problems and write software without knowing the underlying physics necessary to make their software run. On the other hand, this same abstraction puts the IT professional far away from the original Inventive Principles of TRIZ.

Beckmann states that physical and chemical systems have three characteristics under which they use to be analyzed. He claims that IT Systems should also be analyzed under these characteristics, hereafter called dimensions, in order to achieving better results:

- The objects the system consists of

- The characteristics and state of each object
- The interaction between the objects

For IT Systems, objects would be the hardware equipment that process information, characteristics and state of each object would be the data handled by the system and the interaction between objects would be specified by software code. From this definition, we propose to use the same three dimensions, migrated to IT, to model the Acting Trends of Evolution:

- Infrastructure
- Data
- Code

## 4. Trends of Evolution for IT Systems

Under the Checking Trends of Evolution, Software developers should consider whether their system does not violate any of them, as long as for the Acting Trends of Evolution, Software developers should figure out how to evolve their systems under the three dimensions proposed by Beckmann.

### 4.1. Checking Trends of Evolution for IT Systems

**Increased ideality:** Systems evolve to have:

- more benefits (better UI, better user experience (UX), faster, easier to buy),
- less costs (require less maintenance, consume less memory, consume less power)
- less harms (less bugs, less disk failures).

**S-Curve Stages of Evolution:** Systems evolve through the stages set by the S-curve:

1. Does it run? Does it perform its main functionality?
2. Has it already gone to the market? What is needed to turn a software into a product? Got feedback?
3. What should I add to increase ideality (make it faster, better UI, new features...) and attend to market feedback and face competition?
4. What should I remove to increase ideality (decrease memory footprint, decrease power consumption...) and decrease costs to make it simpler and possibly reach a new segment of non-specialized user?

**Non-uniform evolution of parts:** System parts tend to evolve on distinct S-Curves than the System itself. This applies at all level of scales

- Super-system
  - Does required development, testing and runtime environment components evolve separately? (power grid, network, physical space...)
- System
  - Does system history and roadmap show evolution of requirements separately? (usability, performance, scalability...)
- Subsystem
  - Does system history and roadmap show evolution of parts separately? (UI, speed, memory, features...)

### 4.2. Acting Trends of Evolution for IT Systems

For each dimension of each Acting Trend of Evolution, the different degrees of evolution are shown. From them, traditional radar plots can be built to detect which Trend shows the greater potential for evolution.

**Increasing Segmentation:** Systems evolve to become built of smaller yet integrated parts

- Infrastructure:
  - mainframe, distribute processing on LANs, intranet, internet, data centers, cloud computing
- Data:
  - Raw data, primitive data types, homogeneous aggregated types (arrays), heterogeneous aggregated types (structures), abstract data types, extensible data types (classes)
- Code:
  - Monolithic code, subroutines on a single file, subroutines on multiple files, static libraries, dynamic libraries,

**Increasing Dynamism and Controllability:** Systems evolve to become more flexible but this flexibility usually requires more controllability to become useful

- Infrastructure:
  - Individual Servers, Racked machines, Virtual machines, Scalable architecture, Elastic Cloud Architecture
- Data:
  - Static memory allocation, semi-static memory allocation, semi-dynamic memory allocation, dynamic memory allocation
- Code:
  - Monolithic code, subroutines, class methods, generic methods, virtual methods (runtime method lookup)
  - Fixed parameters, manually adjusted parameters, semi-automatically adjusted parameters, partial automatically adjusted parameters, full automatically adjusted parameters
    - responsive User interface, multi-resolution image support, dynamically adjusted communication packet size

**Simplicity-Complexity-Simplicity (mono-bi-poly):** Systems evolve increasing their complexity and then start to simplify again

- Infrastructure:
  - Single server single disk, single server redundant disks (RAID), redundant servers, replicated sites single link, replicated sites redundant links, cloud hosted site
- Data:
  - Sequential files, Random access files, Indexed files, Relational Databases, NoSQL Databases
- Code:
  - Single-threaded algorithms, Single-threaded with background functions, Multi-threaded algorithms, Parallel algorithms, Client-server architecture, Multi-tier architecture
    - connection pools, load balancing, message queue processing,
  - Text mode BW User Interface, Text mode Color UI, Graphic mode UI, No UI
  - Standard features, extended features, custom features, client made features

**Matching and Mismatching:** System evolve to become more (or less) interoperable with other systems

- Infrastructure:
  - Run on one vendor HW, Run on multiple vendors HW, Run on multiple Operating Systems, Run on Multiple HW platforms
- Data:
  - Handle data homogeneously, Handle primitive values more efficiently, support multiple file formats, support multiple communication protocols,
- Code:
  - Single interface, double interface, multiple interfaces, configurable interface
    - Public key cryptography, configurable supported formats

### **Less Human involvement:** System evolution tends to free humans from many repetitive tasks

- Infrastructure:
  - Manual procedures, semi-automated procedures, partially automated procedures, fully automated procedures
    - Manual backup, semi-automated backup, partially automated backup , fully automated backup
    - Manual deploy, semi-automated deploy, partially automated deploy, fully automated deploy
      - self-update
- Data
  - Manual resource release, semi-automatic resource release, partially automatic resource release, automatic resource release
    - automatic file closing, garbage collection
- Code
  - Manual testing, semi-automated testing, partially automated testing, fully automated testing
    - Test automation for quality assurance

## **5. POSWEB System Evolution**

We will now introduce the POSWEB platform for payments. POS payment terminals are very awkward machines that use proprietary application development environments provided by their vendors. To avoid such diversity, we have developed POSWEB, a web browser based on WAP standards that runs on most vendor's terminals.

Throughout the years, besides being ported to other platforms such as PCs and smartphones, POSWEB has gone through a huge evolution, from which we highlight here the main enhancements.

According to the Checking Trends of Evolution, every enhancement suffered by a system should be adherent to all of them, otherwise it must be reassessed in order to be figure out if it really enhances the system.

### *5.1. Checking Trends of Evolution Analysis*

Here we analyze how each enhancement suffered by POSWEB since its creation fitted to the Checking Trends of Evolution.

#### **Increase Ideality:**

- Custom extensions to support POS hardware (printer, mag reader...)
- Multiple POS vendors support
- Chip&PIN Payment support
- Payment legacy protocols support
- Indexed File Access support
- Background Dialing
- Multi-application support
- Application Store support
- Multi-part support
- Self-updating
- Graphic User interface

#### **S-Curve Stages:**

1. Creation
  - a. WAP standards supported on one vendor – 2001
  - b. Custom extensions to support POS hardware (printer, mag reader...) – 2002

2. Go to Market
  - a. Multiple POS vendors support – 2003
  - b. Chip&PIN Payment support – 2004
  - c. Payment legacy protocols support – 2004
3. Increase Features
  - a. Indexed File Access support – 2005
  - b. Background Dialing – 2006
  - c. Multi-application support – 2007
  - d. Application Store support – 2007
  - e. Multi-part support – 2008
  - f. Self-updating – 2010
  - g. Graphic User interface – 2013
4. Decrease Costs
  - a. UI removed – 2017
  - b. Payment service for other Apps – 2018

**Non-uniform Development:**

- Custom extensions (Sub-system)
- Chip&Pin Payment support (Sub-system)
- Indexed File Access support (Sub-system)
- Background Dialing (Sub-System)
- Payment legacy protocols support (Sub-system)
- Multi-part support (Sub-system)
- Multi-Application Support (System)
- Graphic User Interface (System)
- Self-updating (System)
- Multiple POS vendors support (Super-system)
- Application Store support (Super-system)

*5.2. Acting Trends of Evolution Analysis*

Differently from the Checking Trends of Evolution, enhancements to a system are usually driven by one of the Acting Trends of Evolution. Here we can see how those enhancements were originated from the Acting Trends of Evolution.

**Simple-Complex-Simple:**

- WAP Standards (Simple)
- Custom extensions (Complex)
- Chip&PIN support (Complex)
- Payment legacy protocols support (Complex)
- Graphic User Interface (Complex)
- UI removed (Simple)

**Increase Dynamism & Controllability:**

- Background Dialing
- Multi-Application support
- Application Store support

**Segmentation:**

- Multi-part support (code split into DLLs)
- Native controls UI (UI delegated to the OS)

**Match/Mismatch:**



- Multiple POS vendors support
- Multiple Hardware support (PC, mobile)
- Alien Scripting support (java or Lua)

#### **Less Human Involvement**

- Self-updating
- IOT support

### *5.3. Evolutionary Potential Analysis*

System potential for evolution can be easily assessed with radar plots that highlight those Acting Trends of Evolution that are underdeveloped and have more potential for greater benefits.

Figure 1 shows POSWEB radar plot for the very initial version and the current production version. Clearly, there were and there are still many things to improve on all dimensions.

As a mature product, on the last stage of the S-Curve, POSWEB's current movements go toward the increase of ideality by cost reduction instead of direct benefits increase. Following this drive, the next generation for smartphones and smartPOSes has its user interface replaced by a programmatic interface. Removing the user interface dramatically reduces POSWEB maintenance costs and provides native application developers with an API (Application Programming Interface) to request payments as a service from their business applications. With this dramatic change on the system architecture, POSWEB developers can focus their energy on doing better payments besides allowing application developers to write their user interface with the full capacity provided by the operating system, not relying anymore on the features relayed by POSWEB.

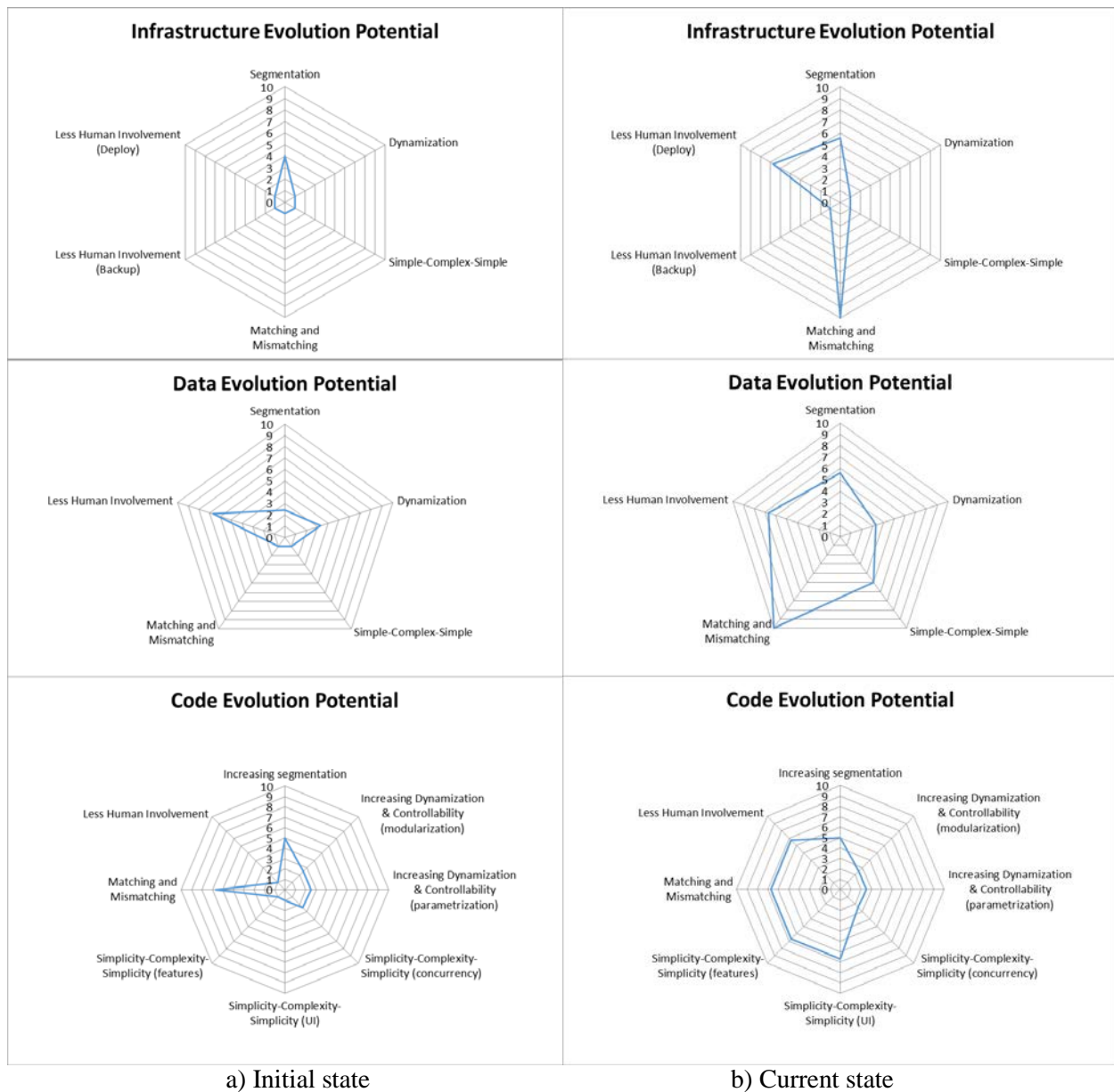


Fig. 1. POSWEB Evolutionary Potential Radar Plot

With the advent of Industry 4.0 [15], POSWEB new service architecture is particularly suitable to the Internet of Things (IOT), where devices should be able to perform transactions and even payments without human interaction.

Figure 2 illustrates the evolution of the POSWEB user interface from its initial version up to its last pre-smartPOS version.



Fig. 2. Initial and Current version snapshot of POSWEB System

## 6. Conclusion

The difficulties met when trying to use TRIZ on Software development have pointed us toward the Trends of Evolution to evolve software. Despite of that, Beckmann's characteristics paradigm is considered by us as the missing link between TRIZ and Software development, explaining the diversity of valid solutions obtained from the same TRIZ recommendation. This diversity is actually due to solutions belonging to distinct dimensions of the same situation.

The main contribution of this work is the proposal of viewing some of the Trends of Evolution under the lens of Beckmann's characteristics applied to Software Roadmap Development. We have classified the Trends of Evolution in Checking Trends and Acting Trends. The former being used to check whether a system does not violate any of them, and the latter to figure out how to evolve a systems under the three dimensions proposed by Beckmann.

We have presented a case of a product that has evolved and is evolving according to model proposed here.

Further research is still needed in order to identify sub-trends that may best suit software evolution on a broader sense. The relation between the Acting Trends of Evolution and TRIZ Inventive

Principles also deserve some attention on future research. The usage of other TRIZ tools to Software development is something that should be more explored.

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**Communicating Author:** [lcguedes.ime@gmail.com](mailto:lcguedes.ime@gmail.com)

**TRIZfest 2018**  
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**TRIZ Modelling of X-Ray Phase Contrast System for Medical Applications**

Tiziana Bertoncelli<sup>a</sup>, Cristina Cozzini<sup>b</sup>, Guido Kudielka<sup>b</sup>, Oliver Mayer<sup>a</sup>

<sup>a</sup>*GE Global Research, Garching bei München, 85748, Germany*

<sup>b</sup>*GE Healthcare, Garching bei München, 85748, Germany*

**Abstract**

Medical Imaging is a fast-developing field with a very high social and human impact: its research goals are the continuous improvement of the diagnostic quality and the patient experience. In x-ray imaging different approaches are explored to improve image quality while reducing the dose delivered to the patient. The traditional approach relies on the x-ray attenuation occurring when x-rays pass through matter. Recently, a novel technology called x-ray phase contrast showed great diagnostic potential. As it retrieves also measurable x-ray phase shift and scattering information, this technology provides high-resolution images with improved contrast of soft tissue. A detailed Six-Sigma study highlighted the need of a radical approach to identify viable system solutions for the x-ray phase contrast system, a potentially breakthrough technology not only for medical imaging, but also for security screening and non-destructive testing. The system, still in its first evolutionary stage, has been thus deeply analysed with different TRIZ tools. This paper presents the results of the overall modelling effort according to different approaches, such as S-Curve, Function analysis for Processes, Contradiction Resolution, Flow Analysis, Trimming, Substance-Field; this analysis allowed to underline the physical challenges, to gain a better system insight and to formulate new possible concepts.

Keywords: TRIZ, Medical Equipment, Functional Analysis for Processes.

**1. Technology Description and TRIZ Analysis**

The Engineering System under investigation is an x-ray grating interferometer [1], used to produce phase-contrast images with x-rays. The main applications are medical imaging (especially mammography), as well as security screening, non-destructive testing and food inspection. All these technologies need to maximize image quality; moreover, for medical applications it is fundamental to keep the radiation dose as low as possible. X-ray phase contrast provides enhanced and complementary information about the specimen with high sensitivity and contrast between healthy and diseased tissues. However, for a successful translation into the clinical field, such an Engineering System must satisfy several requirements to be applicable in a hospital environment, e.g. its footprint must fit in a regular diagnostic room and the image acquisition time must be compatible with medical staff and patients' needs. Current potential limitations to the implementation of this technique are in fact the system complexity, due to presence of three grating in the system, and the long acquisition time, due to a phase stepping procedure which is currently used to extract the signal.

*1.1 A brief setup description of the x-ray interferometer*

The interferometer consists of three in-line gratings (Fig. 1), with a periodic pattern of a few micrometer pitch, which condition the x-ray field. A blocking grating (G0) in front of a standard x-

ray tube produces spatially-coherent sources of radiation. Periodic interference patterns (“fringes”) are generated by a phase grating (G1). These fringes produce a self-image of the phase pattern at certain distances, defined as Talbot distance. At this distance, a detector can collect the amplitude and phase information of the X-ray signal. Since the fringe period is in the order of a few micrometers, it cannot be analyzed by standard x-ray detectors with typical pixel sizes of 100 $\mu$ m or more. Therefore another blocking grating (G2) in front of the detector with the same periodicity as the fringes is shifted perpendicular to the slit direction of the grating [2]. The step size is a fraction of its period and an image is acquired for each step. After sampling the whole period, the measurements for each detector pixel can be described as the convolution of the fringes with the rectangular grating function. Using Fourier analysis, the phase of the fringes can be determined. The described setup has a total system length of 1m between the grating G0 and G2. The gratings were positioned in a symmetric design, generating a self-image of the first Talbot order at 0.5m. The pitch period is defined as 10 $\mu$ m for G0 and G2 and 5 $\mu$ m for G1 and the height is 100 $\mu$ m (G0, G2) and 4.3 $\mu$ m (G1) respectively (microworks GmbH, Karlsruhe, Germany). The image quality criterion for grating-based XPCI is defined by “visibility”, which is given by the ratio of the relative signal amplitude to the total mean signal value of the intensity modulation. It is a critical parameter directly impacting the system sensitivity, i.e. the ability to quantitatively retrieve transverse phase changes. The theoretical visibility of the system was calculated as 48%. The accurate alignment of the interferometer gratings is also important for the image quality. A quantitative assessment of the critical experimental factors has shown a strong effect due to the rotation of the G1 grating around the x-ray beam axis [3]. Furthermore, environmental effects like temperature change and vibration were identified as degrading factors, whereas the spatial positioning of G2 had less influence.

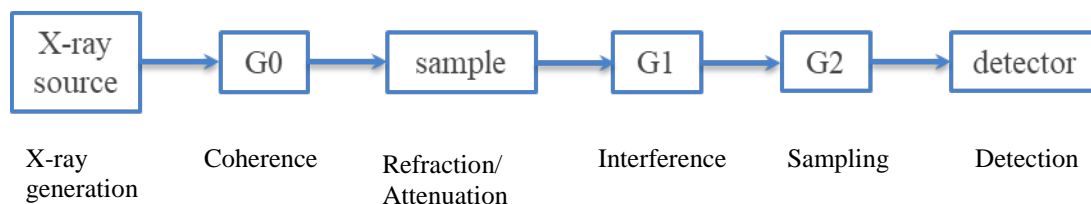


Fig 1. x-ray grating interferometer set up

## 1.2 TRIZ analysis

A TRIZ analysis was performed, to be presented to a team of Subject Matter Experts for a 4-hour brainstorming; due to the limited amount of time allocated, a pre-work session was prepared by the project leader and the TRIZ facilitator. Several modern TRIZ [4] analysis tools were employed: Express S-Curve Analysis, Function Analysis for Processes, Trimming, preparing for the Contradiction Formulation and Idea Generation Phase. The detailed procedure description and the generated ideas discussion will be developed in the next Paragraphs. The TRIZ project was at first defined as follows:

**Object for analysis/improvement (Engineering System):** x-ray grating interferometer for phase contrast imaging

**Project goal:** It is necessary to increase speed and image quality of the measuring system

**Main function:** differentiate between diseased Body Tissues and healthy ones



The Engineering System (ES) can be described by means of the two Main Parameters of Values (MPVs):

MPV 1: Image Quality (“Visibility”)

MPV 2: Image Acquisition Speed

The main restriction is provided by the available space in diagnostic room; ideally the ES could work very well if the detector were placed at infinite distance, but its footprint must not exceed the standard size of a hospital diagnostic room. Another restriction is provided by the acquisition time and the limit on the maximum patient dose that can be delivered by a medical system. Since the Engineering System aims to follow and condition the transformations and operations affecting a single field component, a Function Analysis for processes was considered the most appropriate tool for the problem identification phase; it is presented in Paragraph 3, preceded in Paragraph 2 by considerations derived from the S-Curve Analysis and the Trends. The Flow Analysis is shown in Paragraph 4 and the ideas generated after Trimming and Contradiction Formulation are discussed in Paragraph 5. This project was partly funded by the Bayerisches Staatsministerium für Wirtschaft, Infrastruktur, Verkehr und Technologie under contract number 1330/89265/5/12.

## 2. S-Curve Analysis and Considerations from Trends

Most of the typical indicators for the 1<sup>st</sup> stage:

- the ES is new and has a champion parameter;
- the ES is not yet on the market and is of limited practicality;
- the ES adapts components from other existing systems and integrates with supersystem elements; it combines with alternative systems already on the market;
- ES’ costs outweigh revenues
- MPVs change very slowly

apply very well to the Engineering System under investigation; Fig 2 shows the results of the S-Curve analysis for the two considered Main Parameters of Value, along with the recommendations for the system development.

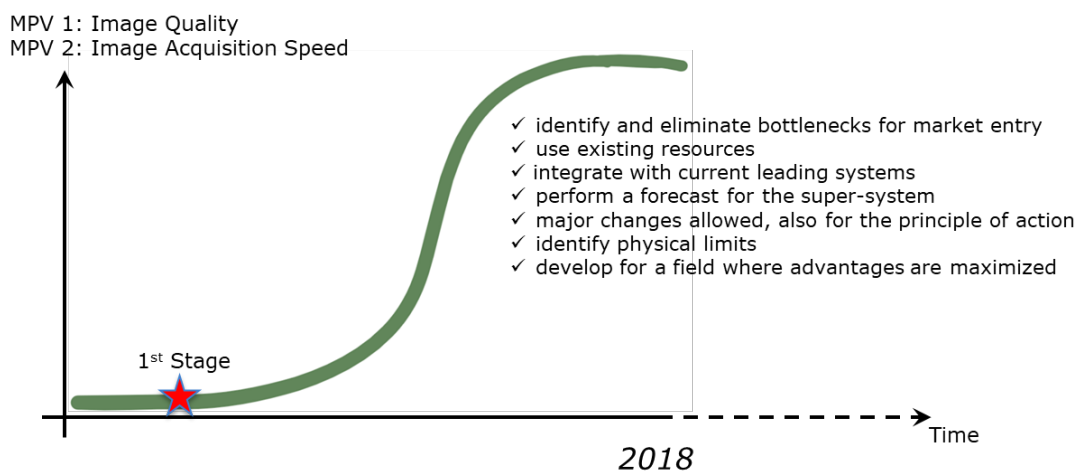


Fig 2. S-Curve Analysis and recommendations

Moreover, it can be observed how the x-ray employment for diagnostics maps to the Trend of Flow Enhancement, in particular the Subtrend 1A [4], that foresees an increase of conductivity of the Flow reducing the number of flow transformations. This suggests the need of a Flow analysis, shown in Paragraph 4.

### 3. Function Analysis for Processes, Trimming and Contradictions

The ES consists presents one target component, the x-ray field, undergoing several transformations; the most suitable analytical tool for a detailed problem identification stage is thus the Function Analysis for Processes. Its components are the Operations performed on the observed target component, the x-ray field, as shown in Table 1:

Table 1: Component Analysis for Processes: List of Operations

System Operations	Supersystem Operations
x-ray Generation	Radiation Shielding
Coherence-Generation	Sample Holding
Interference	Vibration Damping
x-ray Refraction	Vibration Generation
x-ray Attenuation	
Sampling	
Detection	
Dataset Processing	

The resulting Function Model is reported in Table 2.

These analyses allow to identify several Disadvantages, all related to either harmful functions or useful functions performed in an unsatisfactory fashion. They are listed in Table 3 and Table 4 respectively. It can be commented that for Operation “x-ray Attenuation”, due to the interaction between Body Tissue and x-ray, the image quality is reduced, since less photons are able to reach the detector. The “Sampling” Operation taking place in correspondence of G2 causes too few photons to pass through and reach the detector, degrading image quality.

In this case it can be noticed, that for the operation “x-ray Refraction”, the resulting angle is too small; for the operation “Sampling” it occurs that the operation itself is too time consuming, while on the other hand it requires a stepping procedure to read a pitch which is smaller than the detector pixel size. The presented analysis allowed the Operation Ranking and the resulting suggested trimming order built accordingly shown in Table 5, where “Sampling”, occurring at the component *G2-gold on substrate*, where two harmful operations and one useful but at insufficient level are performed, is the first candidate for Trimming. In addition, two Physical Contradictions have been written around the same Operation “Sampling”, reported in Table 6, focusing on the main aspects: one hand the Operations needed to perform the measurement conflict with the time requirements typical of the medical practice, while on the other hand the inspected object “Body Tissue” absorbs photons (the throughput of which enables measuring process), thus degrading the measurement accuracy. Improving the measuring process from the x-ray side conflicts with the need to keep the dose delivered to the patient as low as possible.

Table 2: Function Model for Processes

C: Category: U: Useful, H: Harmful.; P: Performance: N: Normal, I: Insufficient

Operation	Carrier	Action	Object	C	Type	P
x-ray Generation	x-ray source	accelerates	Electrons	U	Productive	N
	x-ray source	produces	Bremsstrahlung	U	Productive	N
	x-ray source	produces	Full x-ray Spectrum	U	Productive	N
coherence Generation	G0	partially blocks	Full x-ray Spectrum	U	Providing	N
	G0	halvens	x-ray Intensity	H		
	G0	reduces	Field of View	H		
Interference	G1	shifts	x-ray Phase	U	Providing	N
x-ray Refraction	Body Tissue	refracts	Full x-ray Spectrum	U	Productive	I
x-ray Attenuation	Body Tissue	reduces	x-ray Intensity	U	Productive	N
	Body Tissue	releases dose	Body Tissue	H		
	Body Tissue	reduces	x-ray Intensity	H		
Sampling	G2	partially blocks	Full x-ray Spectrum	U	Providing	I
	G2	halvens	x-ray Intensity	H		
	G2	reduces	Field of View	H		
Detection	Detector	absorbs	Full x-ray Spectrum	U	Productive	N
Dataset Processing	workstation	extracts	Information	U	Productive	N
Radiation Shielding	Lead walls+Floor	stops	Full x-ray Spectrum	U	Correcting	N
Sample Holding	Patient Bed	supports	Body Tissue	U	Providing	N
Vibration Damping	Optical Table	absorbs	Mech Vibration	U	Corrective	N
Vibration Generation	x-ray source	produces	Mech Vibration	H		

Table 3: List of Disadvantages- Harmful Functions/ Operations

Harmful Operations	Effect
Coherence Generation	G0-gold on substrate halves x-ray intensity
Coherence Generation	G0-gold on substrate reduces field of view
x-ray Attenuation	Body issue releases dose
x-ray Attenuation	Body Tissue reduces x-ray intensity
Sampling:	G2-gold on substrate halves x-ray intensity
Sampling	G2-gold on substrate reduces field of view
Sampling:	G2-gold on substrate blocks full x-ray spectrum: insufficient photon throughput
Vibration Generation	x-ray source produces mechanical vibration

Table 4: List of Disadvantages - Inadequate Useful Functions / Operations

Inadequate Useful Operations	Effect
x-ray Refraction	Body Tissue refracts full x-ray spectrum: the refraction detection is insufficient

Table 5: Recommended Trimming Order

Trimming Order	Operation
1	Sampling
2	Coherence Generation
3	x-ray Attenuation
4	x-ray Refraction
5	Interference
6	Detection
7	Dataset Processing

Other operations identified as most problematic are “Coherence Generation” and “x-ray Attenuation” in correspondence respectively of G0 and the Body Tissue; Engineering Contradictions were thus formulated around G0 and G2, as reported in Table 7.

Table 6: Physical Contradictions from FA for Processes

	Physical Contradiction 1	Physical Contradiction 2
<b>operation</b>	sampling	sampling
<b>should be</b>	performed	performed
<b>In order to</b>	measure x-ray refraction	measure difference, signal shift, amplitude
<b>BUT</b>		
<b>operation</b>	sampling	sampling
<b>should be not</b>	performed	performed
<b>In order to</b>	speed up process	lower patient dose
<b>Recommendation</b>	satisfying contradictory demands	bypassing contradictory demands
<b>Inventive Principles</b>	36. Phase Transitions	25. Self-service
	37. Thermal expansion	6. Universality
	28. Mechanics Substitution	13. The other way round
	35. Parameter Changes	
	38. Strong Oxydants	
	39. Inert Atmosphere	

	Engineering Contradiction	Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
IF	G0 partially blocks spectrum					2. Taking Out
THEN	x-ray becomes coherent					19. Periodic Action
BUT	x-ray intensity is halved					13. The other way round
		x-ray coherence	intensity	convenience of use	loss of energy	chosen: 7. Nesting Doll
						chosen: 9. Preliminary Anti-Action
						chosen: 16. Partial or excessive actions
						chosen: 17. Another dimension
IF	Engineering Contradiction	Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
THEN	G0 partially blocks spectrum					10. Preliminary Action
BUT	x-ray becomes coherent	x-ray coherence	field of view	accuracy of measurement	capacity/productivity	34. Discarding and Recovering
	field of view is reduced					28. Mechanics Substitution
Engineering Contradiction		Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
G0 partially blocks spectrum						23. Feedback
x-ray becomes coherent		x-ray coherence	field of view	stability of composition	capacity/productivity	35. Parameter Changes
field of view is reduced						40. Composite Materials
						3. Local Quality
IF	Engineering Contradiction	Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
THEN	G2 partially blocks spectrum					18. Mechanical Vibration
BUT	detection is enabled	photon selection	intensity	adaptability	loss of energy	15. Dynamics
	x-ray intensity is halved					1. Segmentation
Engineering Contradiction		Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
G2 partially blocks spectrum						35. Parameter Changes
detection is enabled						11. In-advance cushioning
patient receives double dose		photon selection	radiation on patient	adaptability	harmful factor acting on an object	32. Color changes
						31. Porous changes
IF	Engineering Contradiction	Improving - Specific	Worsening - Specific	Improving - Generalized	Worsening - Generalized	Inventive Principles
THEN	G2 partially blocks spectrum					13. The other way round
BUT	detection is enabled	photon selection	detection speed	adaptability	time of action of a moving object	1. Segmentation
	detection is too slow					35. Parameter Changes

Table 7. Engineering Contradictions from FA for Processes

## 4. Flow Analysis


At first a Component Analysis was performed to prepare for the Flow Analysis; the hospital environment was also taken into account, resulting in a rather big component model (Table 8):

Table 8: Component Model - Function Analysis for Products

System Components	Supersystem Components
Power generator	Body Tissue (Target)
Current	Air
Tungsten Filament	Room Walls
Accelerated Electrons	Patient bed
X-Ray Anode	Patient
x-Ray	Room Floor
G0 small Source	Room Light
Coherent x-Ray	
Interference Grid G2	
Gold sampling block	
Coherent x-Ray after G2	
Detector	

Table 9 shows the Flow Analysis for Information, where also the signal post-processing unit and the visualizing/memory device are included.

Table 9: Flow Analysis: Information

Flow	Component	Function	Type	Direction
Information	Power Generator			
	Current			
	Tungsten Filament			
	Accelerated electrons			
	X-ray anode			
	G0 small source	coherence		
	Coherent x-ray			
	Body Tissue		High Channel Resistance	
	G1	interference	Low flow density/ Grey Zone	
	Interference Grid G2		Large number of transformations	
	Sampling Block		Bottleneck	
	Detector		Long flow channel	
	Post-Processing Unit	post-processing	Large number of transformations	



	Monitor	visualizing	Large number of transformations	
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Goal of the ES is the extraction of information from body tissue. In both analyses the most acute operational flow disadvantage occurs at the sampling block and in correspondence of the Body Tissue itself: in this case TRIZ theory suggests that the operation performed by the sampling block should be transferred to some other component removing the spatial/ temporal boundary condition and integrating the sampling/detection/signal processing/visualizing functions in only one component, nowadays belonging to the supersystem. This represents a first inventive problem. The Body Tissue channel resistance improvement represents a second inventive problem.

## 5. Contradictions from Component Analysis for Products

The Component Analysis shown in Table 8 reflected the schema for the Function Analysis for Products, to which the approach for Processes was preferred, as explained in Paragraph 3; this exercise allowed nevertheless to identify some high-level contradictions addressing the Engineering System restriction and limitations discussed in Paragraph 1, that is the system footprint and the dose delivered to the patient. This contributed to shed light on other important opportunities for the further development of the system. One Physical Contradiction (Table 10) and two Engineering Contradictions (Fig. 3) and have been found. It is interesting to notice how the two Engineering Contradictions lend themselves to be modeled by means of different pairs of generalized parameters; for the first one, expressing the conflict between the length of the set-up needed for accuracy and the limitations of the available room lead to no specific Inventive Principle, selecting empty cell of the Altshuller's Matrix.

Table 10: Physical Contradictions - Analysis for Products

	<b>Physical Contradiction</b>
<b>component</b>	detector
<b>should be</b>	far
<b>In order to</b>	enable measurement
<b>BUT</b>	
<b>component</b>	detector
<b>should be not</b>	far
<b>In order to</b>	be built in a hospital room
<b>Recommendation</b>	separating contradictory demands
<b>Direction</b>	separation in time
<b>Inventive Principles</b>	15. Dynamics
	34. Discarding and recovering
	10. Preliminary Action
	9. Preliminary Anti-action
	11. In-advance cushioning

## 6. Generated New Ideas

A brainstorming around the trimming options and the identified inventive principles to solve the contradictions led to the formulation of several ideas, still in conceptual form. The Inventive Principles considered relevant to the problem suggested to act upon three main aspects of the Engineering System: the setup layout (“Taking Out”, “Nesting Doll”), geometry resources of the system (“Parameter Changes”, “Composite Materials”, “Local quality”), segmentation, dynamization and increasing coordination of the x-ray field. In particular, in order to sustain the x-ray intensity after the G0 grating, the grating could be combined with the x-ray source (“Nesting Doll”) or a micro-focus x-ray source might be used (“Taking out”). With the latter the G0 grating can be removed, being a coherent x-ray beam produced by the source itself.

Changing the geometry of the planar G0 grating to a curved design, could address the limitation of the field of view, which would involve design and material changes (“Parameter Changes”, “Composite Materials”). An x-ray tube is commonly a point source, which emits divergent beams in a cone shape. The flat grating imaging suffers from limitations in both the field of view and the flux of photons, especially at the edges where the imaging geometry cannot be approximated to an ideal parallel beams configuration. The use of custom curved gratings thus allows perpendicular incidence of x-rays on the whole grating and gives higher visibility over a larger field of view than a conventional interferometer with flat gratings. Another solution might lay in the grating pattern. Instead of a continuous grating distance, the raster could be different at the edges and at the middle of the grating (“Local quality”).

The need of the G2 grating and the stepping procedure, causing the harming action of reducing the photon flux, could be solved by increasing the detector resolution and hence by decreasing the pixel size (“Segmentation”), resulting in a faster image acquisition and reduced patient dose. However, a balance between spatial resolution and x-ray absorption efficiency of the detector is very challenging to achieve without increasing complexity and cost of the detector module itself. Using magnification by moving the detector further away from the G2 grating, could be another solution (“Dynamics”). However, the detector would need to move to the original position for the absorption image before moving to its second position for the refraction detection. Furthermore, the G2 grating could be integrated into the detector and the detector chip is moving instead of the grating (“The other way around”), which might improve the signal acquisition time.

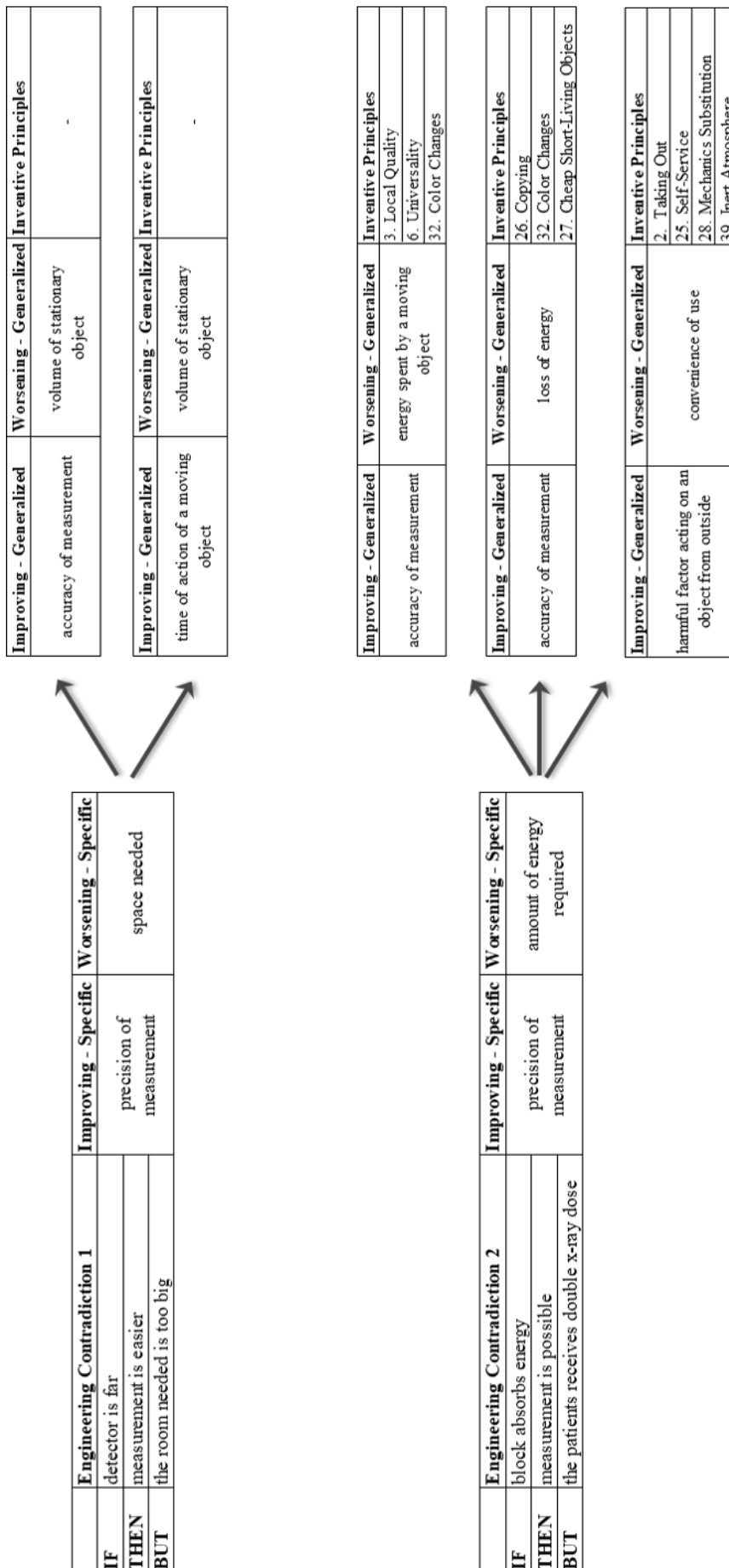


Fig. 3 Engineering Contradictions -Analysis for Products

## 7. Conclusions

A thorough TRIZ Analysis was performed for an x-ray phase contrast system for medical applications, aimed to generate ideas enabling the industrial implementation of this technology and its application in regular medical practice, following a New Product Introduction approach. From the methodological point of view, the modern TRIZ workflow [4] was followed, integrating considerations emerging from tools like S-Curve Analysis, Functional Analysis, and Flow Analysis; the problem-solving stage took advantage of the classical tool like Engineering and Physical Contradictions. The Function Analysis (FA), being focused on operations, was built for Processes in order to reflect the physical behavior of the system, leading to potentially more disruptive solutions; the component analysis for products, built prior of the Flow Analysis for products, allowed to take advantages from the two points of view, focusing on high level contradictions rather than the physics fundamentals.

The generated ideas were aimed to maintain the Principle of Operation; still they introduced major changes in the Engineering System, that can be accepted in accordance with the S-Curve recommendations, since the system under investigation still finds itself in the first evolutionary Stage.

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**INDICATING SYSTEM VULNERABILITIES  
WITHIN CECA MODEL**

Jerzy Chrzęszcz<sup>a,b</sup>

<sup>a</sup> *Institute of Computer Science, Warsaw University of Technology, Warsaw, 00-665, Poland*

<sup>b</sup> *Pentacomp Systemy Informatyczne S.A., Warsaw, 02-222, Poland*

## **Abstract**

It was shown during the TFC 2016 conference, that the structure of a Cause-Effect Chains Analysis (CECA) diagram may be converted into a set of Boolean functions, reflecting the logical relations between the disadvantages. Another approach, aimed at quantitative extensions to the CECA method using a risk management perspective, was presented during the TRIZfest 2017 conference. It was also demonstrated, that propagation of causality within a linear chain of disadvantages is analogous to dealing with risk factors (hazards) and vulnerabilities (weaknesses) within a system. This paper focuses on indicating vulnerabilities of a system to stimulate generation of innovative solutions.

Keywords: Cause-Effect Chains Analysis, Boolean algebra, logical model, vulnerability, negation.

## **1. CECA and Logical Model**

Cause-Effect Chains Analysis (CECA) is a procedural method for determining and documenting causal relations in the analysed system [1, 2, 3]. It starts with indicating drawbacks identified in the system (*target disadvantages*), removal of which is the goal of the project. Then their causes (*intermediate disadvantages*) are investigated one after another, until the primary causes (*root causes*) that remain beyond control are found, such as the laws of nature or specific constraints of the project. Because of their characteristics, the root causes may not be literally eliminated. Therefore the CECA procedure aims at indicating the *key disadvantages* instead, which are deep causes of the target disadvantages.

CECA analysis is documented with a directed graph containing nodes (vertices) of two types and edges (arcs) depicted as arrows, indicating the flow of causality. The boxes reflect disadvantages and a linear chain of disadvantages constitutes a basic building block of a CECA diagram. Such chains (branches) may be connected on inputs (with common causes) or on outputs, with logical operators reflecting trigger conditions. An OR operator describes a logical sum (*alternative*), i.e. any input cause alone or any subset of input causes is sufficient to trigger the output disadvantage. An AND operator describes a logical product (*conjunction*), i.e. all the input causes must be active to trigger the output disadvantage.

The concept of transformation of a CECA diagram into a logical model was presented in [4]. It relies on decomposing the diagram into a context-dependent layer (specific box descriptions) and a context-independent layer (structure of interconnections, including AND / OR operators). Logical model of the structure may be systematically analysed and minimised using methods based on Boolean algebra while active / inactive causes are represented by 1s and 0s, respectively.

Such approach allows for evaluating properties of the model, which may be useful for supporting decisions concerning candidate changes, as well as for answering questions regarding for example the influence of a given cause on the target disadvantages or indicating the most impactful causes.

Significant enhancements to this concept were introduced in [5], together with the quantitative extensions of the CECA model and a generic procedure supporting selection of the most important disadvantages and the most promising candidate solutions using risk management perspective. It was also demonstrated, that propagation of causality within a linear chain of disadvantages is analogous to dealing with risk factors (external hazards) and vulnerabilities (internal weaknesses) of the components involved in development of the disadvantage. Proposed improvements included unified modelling of linear chains and simple loops as well as provisions for modelling of removal of the intermediate disadvantages without removing its predecessors.

Another approach using methods coming from computer science is modelling a CECA diagram as a state machine or automaton [6]. The diagram is perceived as a scheme of *harmful processes* connected by common causes or logical operators, which “produce” target disadvantages in a repeatable way. The proposed conversion uses *parameter-function* perspective devised in [7], also known as *condition-action*. Interactions between objects described in the CECA diagram are transformed into *states* of the state machine model and the conditions are transformed into conditional *transitions* between these states. This conversion translates a CECA scheme into a dynamic representation, which may be described in UML and other standard notations.

## 2. CECA Model and Vulnerabilities

Building a CECA model, we assume that in a linear chain  $X_i$  causes  $X_{i+1}$ , so that *if  $X_i$  then  $X_{i+1}$*  and we also assume that elimination of  $X_i$  eliminates  $X_{i+1}$ , which is equivalent to *if not  $X_i$  then not  $X_{i+1}$* . This is why we look for the key disadvantages to develop solutions allowing for elimination of whole chains of intermediate disadvantages leading to the target disadvantages. Properties of linear chains are analysed in [8] and a stormy online discussion accompanying this paper suggests that there were several doubts regarding its subject. It seems that important source of confusions and misunderstandings expressed in the discussion is the duality of the approach offered by CECA. In addition to *indirect* (remote) elimination method described above, it is also legitimate to break the chain of causality by removing an intermediate disadvantage *directly* (locally), without taking care of its predecessors.

This duality creates a puzzle of having a single and only one cause identified in the model during the analysis and still being able to get rid of the next disadvantage in the chain without eliminating this sole cause. As the term “cause” appeared too narrow, it was broadened to “control” in [5] and the conflicting requirements regarding disadvantages in a linear CECA chain (excluding the root causes) were described in the form of a physical contradiction:

- each disadvantage should have *exactly one control* to keep the model consistent with the diagram indicating single arrows between the boxes, BUT
- each disadvantage should have *more than one control* to keep the model consistent with the concept of removing a disadvantage without eliminating its predecessor.

A logical representation of a linear CECA chain proposed in [5] was developed as a solution to this contradiction and it contains a cascade of AND gates having one input connected to the output of the previous gate and the other input controlled by an independent variable, as shown in Fig. 1. The first input is used for propagating information about the deeper causes and the second input affects a given disadvantage directly. If any of the inputs are inactive, the output is inactive as well, simulating indirect and direct removal of the disadvantage.

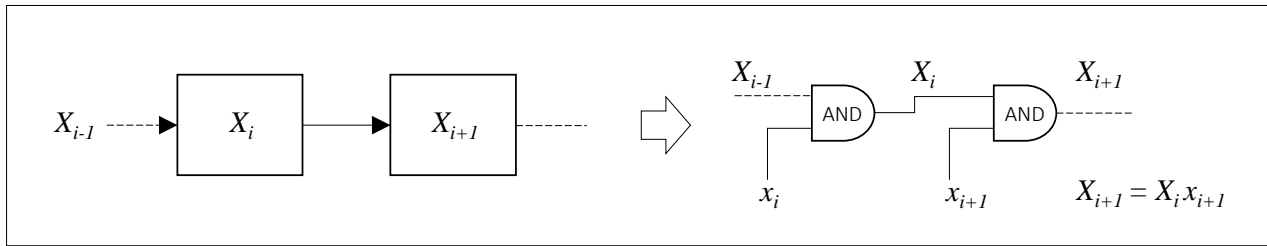


Fig. 1. Chain of AND gates modelling a linear branch of a CECA diagram [5]

This structure properly justifies the possibility of removing an intermediate disadvantage irrespectively of the manifestation of the previous disadvantage. Such arrangement brings no visible improvement (in terms of the outcome) when the previous disadvantage is inactive, because given disadvantage would also be inactive due to the indirect removal scheme (*if not  $X_i$  then not  $X_{i+1}$* ). But it becomes interesting when the preceding disadvantage is active, because in this situation it allows for disabling propagation of the causality down the chain.

From the perspective of risk management, the preceding disadvantage in the chain is similar to a *risk factor* or hazard, while the additional control affecting the propagation of the harm caused by this hazard is similar to a *vulnerability* or a weakness of the system. For instance a sharp object lying on the road creates a hazard of a puncture to a vehicle tire, while the properties of the tire, e.g. self-sealing, may make it invulnerable (immune) to punctures, so that a vehicle retains its mobility at the acceptable level in spite of the encountered hazard.

According to a formal ISO definitions [9]:

- **vulnerability** is a weakness of an *asset* or *control* that can be exploited by one or more *threats*,
- **controls** are means of managing *risk* (of administrative, technical, management or legal nature),
- **asset** is anything that has value to the organization,
- **risk** is effect of uncertainty on objectives,
- **threat** is potential cause of an unwanted incident, which may result in harm to a system or organization.

And in the environmental perspective [10]:

- **vulnerability** is a degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a *hazard*,
- **hazard** is a threat to a system, comprised of *perturbations* or *stress* and the consequences they produce,
- **perturbation** is a major spike in pressure beyond the normal range of variability in which the system operates,
- **stress** is a continuous or slowly increasing pressure, commonly within the range of normal variability.

Informally: risk is associated with the potential that hazards (threats) could exploit some existing vulnerabilities and thereby cause harm to an organization, systems, subsystems or components. Although the terms “risk” and “vulnerability” are closely related and a similar approach is often taken for their identification and evaluation, they differ in the way they participate in the process.

In particular, vulnerability – contrary to a risk factor – is not a “cause” in the common sense, as it cannot create a disadvantage by itself, but it may attenuate (or amplify) the unwanted effects brought to the system by a hazard. Therefore *risk assessment* usually focuses on the external factors potentially affecting the system, while the *vulnerability assessment* addresses the properties of the system influencing its ability to withstand these harmful factors.

The concept of vulnerability is broadly known and explored within the IT area. Computer systems use complex hardware and software components and they communicate with users and other computers using various interfaces and protocols. One of the typical patterns of cyberattacks is to use a known error or a specific property of a particular software component to get a privileged access to a computer system. Such a “security hole” is actually a vulnerability, which may be “patched” by installing a fixed (secured) version of a vulnerable component.

Same duality is also observed in SWOT analysis, widely used in business for supporting decision making. The analysis focuses on assessing four aspects of a situation: *Strengths*, *Weaknesses*, *Opportunities* and *Threats* (hence the name):

- **strengths** are internal factors perceived as advantages (assets, resources, etc.),
- **weaknesses** are internal factors perceived as disadvantages (e.g. insufficient experience),
- **opportunities** are external factors perceived as potential advantages (i.e. chances),
- **threats** are external factors perceived as potential disadvantages (i.e. risks).

These areas are usually presented as a 2×2 matrix, as shown in Fig. 2, because such form helps in seeing the whole picture of a situation. The vertical axis reflects the origin (internal vs. external) and the horizontal axis reflects the nature of a perceived impact (positive vs. negative). This approach strongly correlates with the risk management perspective mentioned before, as it refers to the threats (negative factors coming from outside) and the weaknesses (negative factors present inside).

Interestingly, the SWOT matrix also appears very much TRIZzy. First, a two-dimensional model reflecting *system* and *super-system* properties clearly reminds us of the System Operator. Next, used categorization of impact maps directly onto *useful* and *harmful* interactions. Finally, the situation is described in a relative, context-dependent way, taking into account the intended outcome.

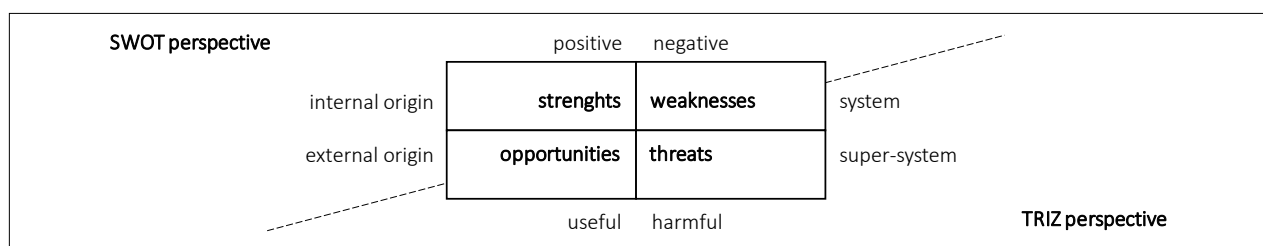


Fig. 2. SWOT matrix reflecting four aspects of a situation – original perspective and TRIZ perspective

### 3. Indicating Vulnerabilities in CECA Model

It seems that, in spite of its generic nature, the concept of vulnerability has not been explicitly used in TRIZ literature so far. Only a few referrals have been found and all of them were related directly to the IT domain. On the other hand, the approach of *negation of undesirable action statement* [11] appears similar, as it uses the cause-effect chain to *negate* a description of each of the disadvantages and tries to solve all the problems defined by such inverted statements. This concept was enhanced in [12] by narrowing the problem definition context to two consecutive disadvantages in the chain and looking for a solution aimed at avoiding the harmful effect when the cause



of harm is active, which resembles vulnerability patching by making the system immune to hazards.

Another similarity comes from the differentiation of the causes recorded in a CECA diagram. One of the recommendations provided in [2] is to distinguish *properties* and *actions*. A similar separation is also proposed in [7], with a structural recommendation to build cause-effect chains with interleaved nodes describing *conditions* and *actions*. In both cases a distinction is made between interactions of objects and the influence of these interactions on the states of the objects, described by the values of specific parameters. There is also an interesting entry in the discussion accompanying [3], which recommends that instead of asking if A causes B one should rather check if A *always* causes B (i.e. if A is a sufficient condition for manifestation of B) and if this is not true – consider the formula *if (A and X) then B* to either identify the X or admit that the origin of B is not quite clear. The X symbol reflects a factor capable of enabling or disabling the harmful interaction, which is equivalent to vulnerability.

This section may be concluded with the following guidelines for identifying vulnerabilities in a CECA model:

- each box describing a disadvantage in a linear chain should have, as a rule, an additional control assigned for modelling respective vulnerability,
- in the logical model the cause (input of the original box) and the vulnerability control must both be active to generate the effect (output of the box), i.e. AND operator should be used,
- some disadvantages included in the original CECA model (especially those feeding AND inputs) may actually reflect vulnerabilities, i.e. refer to objects of the harmful interactions.

## 4. Example

Let us take a closer look at the example of a tire puncture, which was mentioned before. The target disadvantage is that a *vehicle stops because of a flat tire* and the linear chain of causes is shown in Fig. 3a. Using the rules indicated in the previous section, we may enrich the diagram by indicating the vulnerabilities which enable propagation of the causes through the AND gates (Fig. 3b).

The immunity to the harmful factors may be achieved in different ways (Fig. 3c) – we may use external or internal protection to avoid the puncture, we may use self-sealing features to avoid loss of pressure, or we may use reinforced sidewalls or a ring of semi-rigid substance to provide sufficient support for the vehicle in case of the pressure loss. We may also change the paradigm and use the airless tires that support a vehicle due to the stiffness of the rubber-like materials rather than integrity of compartments filled with pressurized gas. Such tires are actually used in heavy machines working in adverse conditions with high risk of puncture (mines, demolition sites, etc.).

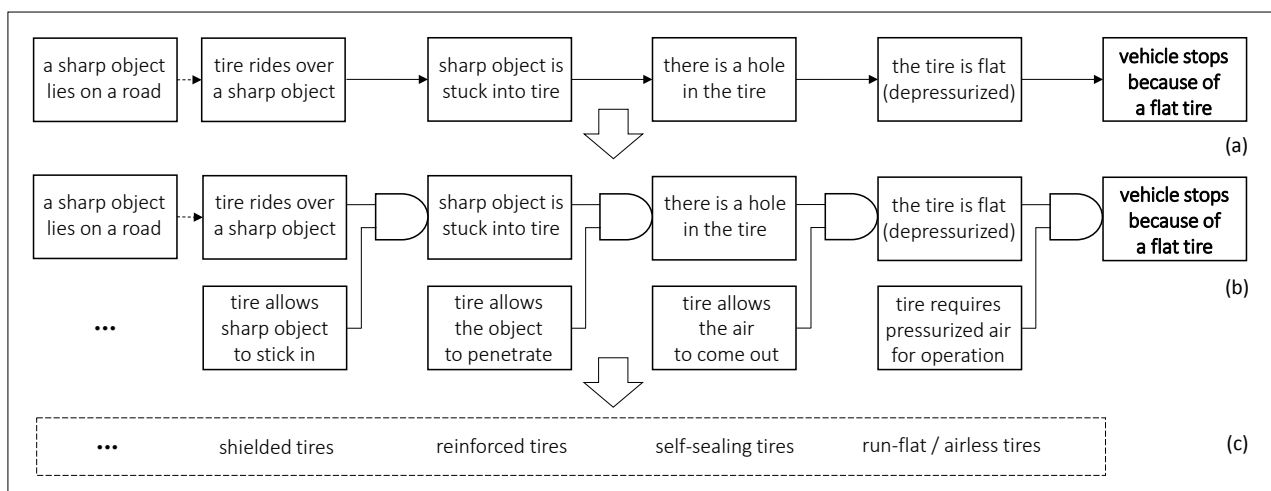


Fig. 3. A sample cause-effect chain (a), the same chain with disclosed vulnerabilities (b) and the candidate solutions generated by negating descriptions of the vulnerabilities (c)

## 5. Conclusions and Further Work

This paper presents the concept of vulnerability in the context of the cause-effect analysis. Distinguishing the risk factors (hazards incurred by the carriers of harmful interactions) from the vulnerabilities (weaknesses related to the objects of these interactions) allows for consistent description of both indirect and direct removal of the disadvantages from a CECA diagram. The guidelines proposed for identifying vulnerabilities in a CECA model cover the hidden vulnerabilities implied by the disadvantages and the vulnerabilities explicitly included in the original model. Such approach increases the chances of better understanding of a problem situation and indicates the directions of search for candidate solutions aiming to eliminate the vulnerabilities.

Further research could address two topics implied by this and the author's previous papers regarding CECA extensions, namely: scope of applicability of logical negation in a qualitative CECA model and merging logical negation with a quantitative model of causality.

## Acknowledgements

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Communicating Author: **jch@ii.pw.edu.pl**

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**APPLICATION OF TRIZ METHODS FOR ALTERNATIVES ON  
CARDIAC ACTIVITY DETECTION IN MAGNETIC RESO-  
NANCE IMAGING**

Guido Kudielka<sup>a</sup>, Tiziana Bertoncelli<sup>b</sup>, Oliver Mayer<sup>b</sup>

<sup>a</sup>*GE Healthcare, Garching b.M., 85748, Germany*

<sup>b</sup>*GE Global Research, Garching b.M., 85748, Germany*

## **Abstract**

In cardiac magnetic resonance imaging (MRI), the acquisition of the heart activity is required to trigger the imaging process and is critical for image quality. Electrocardiography (ECG) is typically used to detect the electrical activation of the heart cycle. Due to the magnetic field of the MRI, the magnetohydrodynamic effect (MHD) due to the ions dispersed in the aorta blood leads to a falsified ECG signal and to incorrect trigger timing. With the current trend to higher magnetic field strength, the MHD effect is an increasing issue for signal stability and image quality.

A thorough analysis of the system by applying TRIZ methods like S-Curve analysis, Functional Analysis, Contradiction Resolution and Trimming, describing the abstract problem and defining abstract solutions, allowed to recognize how existing technologies implement TRIZ concepts. To find alternative solutions for acquisition of the heart activity, we have analyzed the current technology model, describing the interaction between electromagnetic properties of biological tissue with the electronic components of the medical device. For one trimming solution, a prototype was designed and a volunteer study with six subjects was performed and compared to ECG.

Keywords: TRIZ, Medical Equipment, cardiac MRI, ECG

## **1. Introduction**

### *1.1. Magnetic Resonance Imaging in a nutshell*

Magnetic resonance imaging (MRI) was conceived in the 1970s and has become an important diagnostic device especially for soft tissue investigation [1]. It is based on the phenomenon of nuclear magnetic resonance (NMR), which can be observed if nuclei with non-zero nuclear spin are exposed to a strong external magnetic field  $B_0$ . Most prominently, a precession of the spin system can be observed, and using radiofrequency pulses, energy can be exchanged with it. The

spin system will however return from the excited state back to thermal equilibrium, according to a process called „relaxation“. As the energy exchange process is strongly influenced by the physico-chemical environment of the spin system (i.e. density, viscosity, temperature, aggregate state, susceptibility, etc.), measuring these relaxation processes allows inferring about the system properties.

In MRI the process of excitation and relaxation is accompanied by a slight modification of the magnetic field along the three orthogonal axes (x-, y- and z-axis). This so-called gradient fields alter the spin frequency as well as its phase and enable a spatial encoding of the received radiofrequency energy of the spin systems. The whole process of excitation, spatial encoding and data acquisition in the relaxation phase is called pulse sequence and acquires typically on line of the image. Hence this pulse sequence needs to be repeated according to the number of lines of the image or pixel matrix. Its temporal duration depends on the kind of medical investigation and anatomy. For example, a matrix size of 256x256 pixels and a pulse sequence length of one second would take 256 seconds or 4 minutes, 16 seconds for the acquisition of the complete image. The final image is obtained in a reconstruction process by a Fourier transformation of the spatial encoded frequency and phase information.

Due to this long acquisition time, MRI is sensitive to motion. Especially in cardiac magnetic resonance imaging (CMR) continuous physiologic motion needs to be considered. This is because the movement of the heart, diaphragm, and neighboring organs produce artifacts in the obtained images, such as ghosting and blurring [2]. This problem is typically solved by cardiac triggering through electrocardiography (ECG) or peripheral pletysmography (PPG) and respiratory gating or monitoring using a pneumatic belt or motion detection sequences, so called navigators. With cardiac triggering, the image acquisition is synchronized with the cardiac cycle, resulting in an image of a specific cardiac state without or reduced motion artifacts.

### *1.1. The challenge of cardiac triggering in MRI*

ECG and PPG can be used to implement a trigger relative to the electrical activity of the heart and the pulse wave in the peripheral arteries, respectively. At ultra-high fields ( $B_0 \geq 3T$ ), due to the magneto-hydrodynamic (MHD) effect, the ECG is distorted by voltages induced by the blood flow in the heart and aorta [3]. This can make ECG triggering challenging. PPG sensors are not affected by MHD distortions, however are sensitive to sensor positioning, skin temperature and peripheral blood perfusion.

In practice, ECG is the preferred trigger source and cardiac MRI is mostly performed on 1.5T systems, on which the MHD has only minor influence. To enable robust cardiac MRI at higher field strength, a whole TRIZ workflow has been applied to the system, being the project goal defined as: “it is necessary to increase reliability of the cardiac triggering”: the system must be MRI-compatible and insensitive to radiofrequency electromagnetic oscillations and magnetic fields. The Engineering System “cardiac MRI system” is designed to perform the following main functions:

Main Function 1: synchronize imaging acquisition subsystem

Main Function 2: visualize heart structure

Main Function 3: acquire heart function signal

The following paragraphs will describe the entire TRIZ workflow, from the problem identification Process (Function Analysis, Cause-Effect-Chain Analysis, Trimming) to the problem-solving

phase (Contradictions). A specific solution implementation will be presented, as well as some literature study of existing solutions according to a TRIZ interpretation.

## 2. Analysis of the MRI System for Cardiac Imaging

### 2.1. S-Curve analysis and Observations from Trends

ECG diagnostic technology is approaching maturity and it can be considered at the end of the 2<sup>nd</sup> Stage of its evolution. In this paper its combined use as triggering tool for CMR technology is discussed, as well the need for the next improvement step, which requires the adoption of alternative solutions for image acquisition [10-12]. Those solutions are still in the research and development phase, during which prototypes and technology demonstrators are being tested.

The Main Parameters of Values (MPVs) for a new CMR triggering solution were defined as:

- Insensitivity to magnetic and radio-frequency fields
- Accuracy of trigger timing
- Consistency of trigger detection
- Convenience for the user

The S-Curve analysis for the MPVs shows, that these technologies lie on the transitional stage, confirmed by express S-Curve analysis in Innovation Navigator™ software. It allows to quickly identify where the Engineering System belong along the S-Curve evaluating the main S-Curve indicators [13], such as presence in the market and MPVs evolution. In fact for the investigated system we can observe that:

- the MPVs grow quickly;
- the system is nearly ready for the market, yet vulnerable to external factors;
- attempts to implement the system in various fields have limited success.

The main recommendations for this stage are:

- the system must be launched to the market as soon as possible
- all parameters must be acceptable and one excellent
- develop the system in the field where the excellent parameter is most important
- big changes to the system are acceptable, but not on the principle of action

The sought for solution addresses a need reflected by the Trend of Increasing Coordination. This is consistent with the observation that the development of solutions in the healthcare space aims to address different aspects, such as 24/7 monitoring needed, progressive miniaturization, integration in everyday clothing, mapping to the Trends of Transition to the Supersystem, Increasing Coordination and Increasing Controllability.

### 2.2. Component analysis

The focus of the analysis was on new sensor technologies for cardiac motion detection. Self-imaging opportunities were not considered, hence the image acquisition system as well as all physiological and electro-physiological were defined as Supersystem Components (Table 1). The component “Aorta-Blood-Electrolytes” describes the blood volume in the Aorta after heart contraction. The System Components were reduced to components at or close to the patient, which finally resulted in a list of 16 elements.

Table 1

Component Analysis of a Cardiac MRI System

<b>System Component</b>	<b>Supersystem Component</b>
MRI RF coil	Image acquisition system
MRI main magnet coil	Heart structure
Trigger signal	Heart function
ECG paddles	Aorta-Blood-Electrolytes
ECG signal analyzer	ECG signal
MRI static magnetic field	Cardiac electrical field
MRI RF field	Heart blood
MRI gradient coil	MHD

### 2.3. Function Analysis

Figure 1 shows a graphical interpretation of the interaction matrix. The static magnetic field aligns the hydrogen proton of the heart tissue and heart blood. The MRI RF field and MRI RF coil interact with each other and the physiological tissue in two directions. First a RF field is generated by the coil which excites the protons in the heart tissue and blood. Consecutively the relaxation process of the protons generates an RF field which is acquired by the RF coil and transferred to the image acquisition system. In modern MRI imaging, excitation and reception of the RF signal is performed by two different RF coils, however the technical principle is the same and hence it was combined in the Function analysis.

Since physiological tissue is a conductive media, it couples inductively and capacitively with the RF coil [4]. This “loading” effect decrease of the coils performance and was defined as a harmful function in the model. This effect is given and can partly addressed in the coils design.

The ECG triggering is shown as a serial connection of interactions. The ECG paddles acquire the cardiac electric field and transfer this ECG signal to the ECG signal analyzer. This signal analyzer detects the R-peak of the ECG signal and generates a trigger signal for the image acquisition system. The main magnetic field introduces a force on the electrolytes of the blood in the aorta and the electrolytes are deflected. This causes a shift of the electric potentials and generate the so called magnetohydrodynamic (MHD) effect. The MHD changes the electric field such, that the ECG signal shows elevated T-wave. The ECG signal analyzer misinterprets the elevated T-wave as an R-peak, which leads to an insufficient trigger generation and hence an insufficient image acquisition.

The harmful and insufficient functions are listed in Table 2.

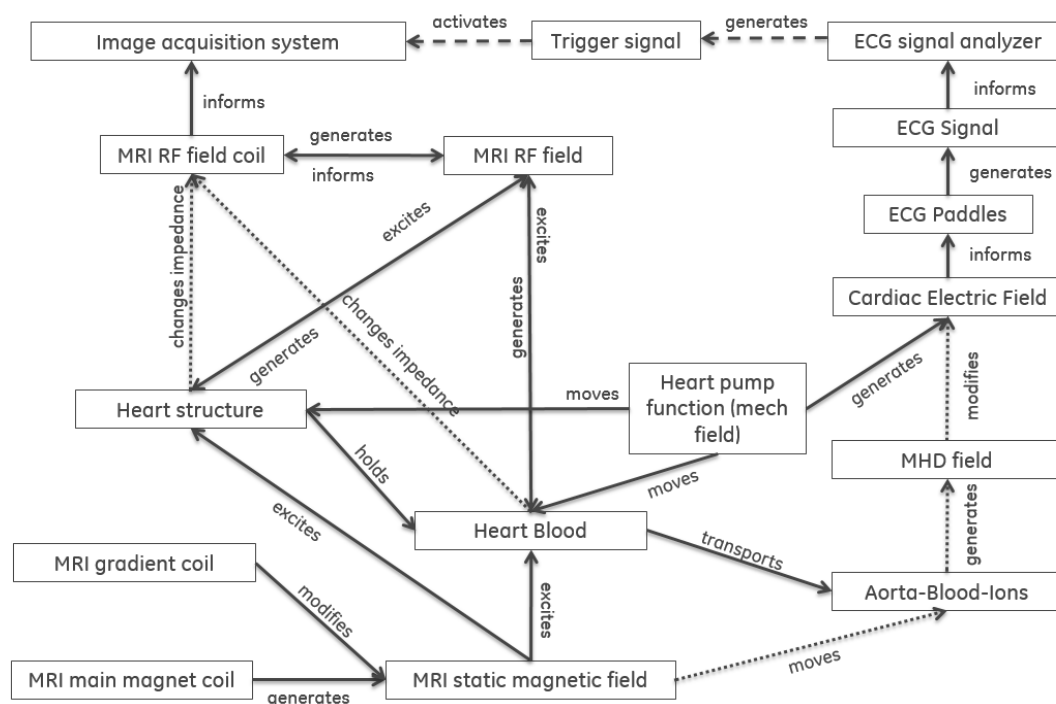


Figure 1: Graphical Function model of a cardiac MRI system; solid line = useful function, dashed line = useful, but insufficient function, dotted line = harmful function

Table 2

### List of Harmful and Insufficient Performed Functions

Harmful functions	Useful Functions (I)
Heart structure couples MRI RF coil	Trigger signal activates Image Acquisition System
MRI static magnetic field moves Aorta-Blood Electrolytes	
Aorta-Blood Electrolytes generate MHD	ECG signal analyzer generates trigger signal
MHD modifies Cardiac electrical field	
Heart Blood couples MRI RF coil	

## 2.4. Cause-Effect Chains Analysis

The project goal was increase the reliability of the cardiac triggering in CMR. The inverted project goal represented the Initial Disadvantage from which the chain was built. The serial flow-down shown in Fig. 2 captures the complete chain, including all the intermediate steps. CMR images are not acquired correctly by the image acquisition system, due to falsified trigger events. These are generated by the ECG signal analyzer, which misinterprets the ECG signal. The MHD effect modifies the ECG signal and is caused by interaction of the static magnetic field with the electrolytes of the aortic blood. Hence the key disadvantage was identified as “MRI static magnetic field moves Aorta-Blood-Electrolytes” and the key problem can be



formulated as “How to eliminate the effect, in which the magnetic field moves the blood electrolytes?”. The following Problem-Solving stage focused on this aspect.

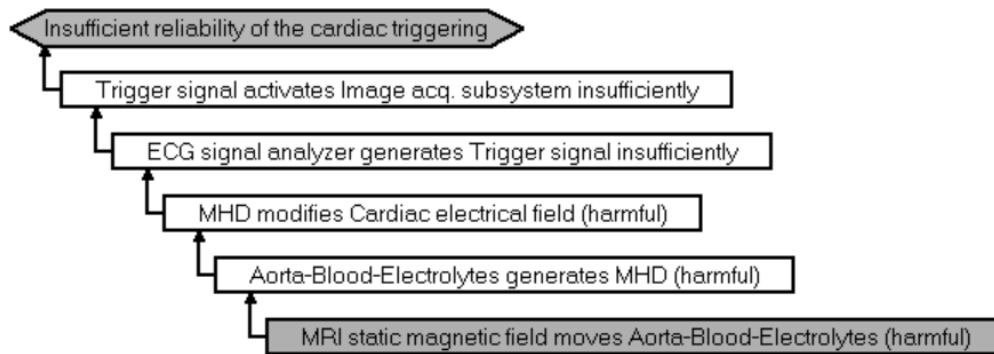


Figure 2: Cause-Effect Chain Analysis of insufficient cardiac triggering; Key Disadvantage: MRI static magnetic field moves Aorta-Blood Electrolytes

## 2.5. Contradictions and Trimming

As shown in the CECA, the magnetic field interaction with the blood electrolytes is the main cause for cardiac trigger instability. However, these effects are physical phenomena and cannot be avoided, if the capability of MRI imaging should be retained. The problem was addressed by means of two main TRIZ tools. At first a physical contradiction was formulated:

The static magnetic field should be present in order to enable MRI imaging

BUT

The static magnetic field should not be present in order to maintain the ECG signal

The second adopted approach was trimming; the suggested trimming order suggested by the function ranking was: 1- MRI static magnetic field 2- ECG signal analyzer 3- trigger signal 4- MRI magnetic coil 5- MRI gradient coil 6- ECG paddles 7- MRI RF coil. Following this classification would mean challenging the principle of operation, the path is not practicable within the scope of the project and is not recommended by the S-Curve analysis of Paragraph 2.1.

Nevertheless, the ECG paddles represented an interesting possible trimming opportunity in the cardiac triggering path. The action “informs ECG signal analyzer” should be fulfilled by another element of the system. Since the MRI RF coil interacts with the heart tissue and blood via loading effects, this element was identified as the new function carrier for the cardiac signal. The inventive problem after trimming was: “How to make “MRI RF coil” perform Function “informs ECG signal analyzer?” The function model after trimming is shown in Fig. 3.

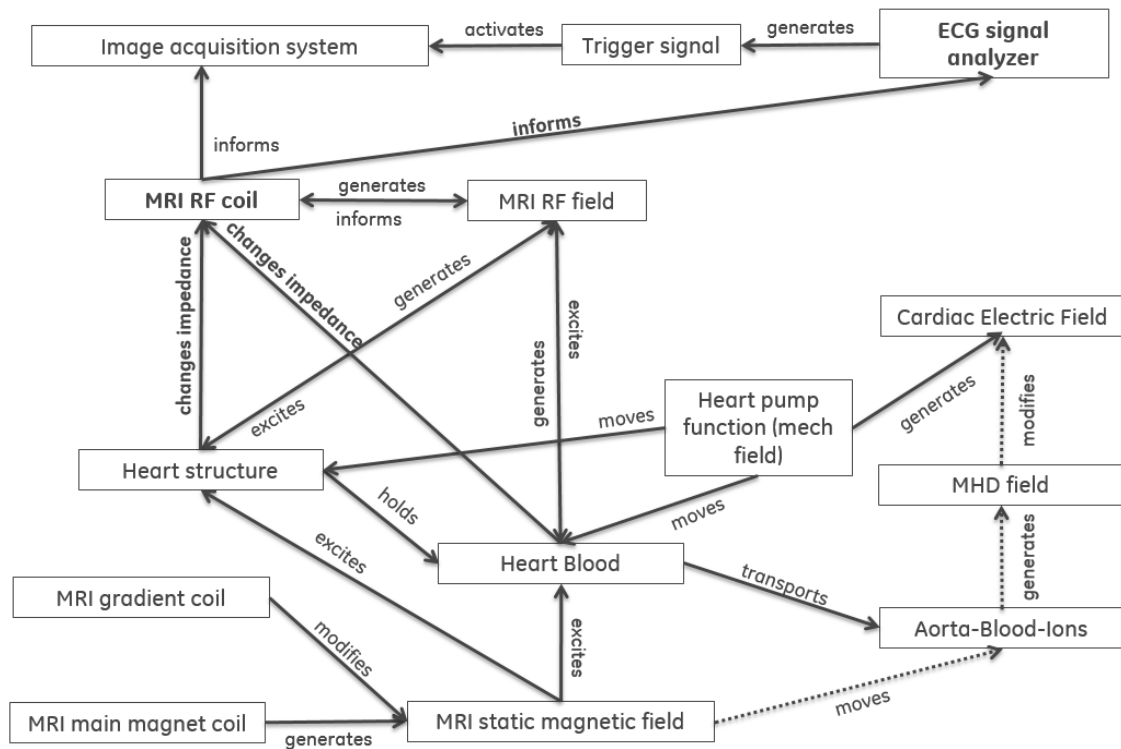


Figure 3: Function model after trimming. The MR RF coil has to inform the ECG signal analyzer, after the ECG paddles and subsequent elements were trimmed; solid line = useful function, dashed line = useful, but insufficient function, dotted line = harmful function

## 2.6 Solutions for identified Key Problems

Two inventive problems resulted from the problem-solving stage, as mentioned before:

Inventive Problem 1 (from the physical contradiction): “How to eliminate the effect, in which the magnetic field moves the blood electrolytes?”

Inventive Problem 2 (from trimming): “How to make "MRI RF coil" perform Function "informs ECG signal analyzer?”

The solution of the first problem emerged while trying to solve the physical contradiction by separating contradictory demands, applying the inventive principle 19-Periodic Action. Such solution would require a switched main magnetic field, which is only active during the image acquisition process. This is challenging since high magnetic fields (up to 7T and more) have to be turned on in milliseconds and the magnetic field homogeneity should reach <1ppm in the field of view. Albeit these limitations, publications have shown the feasibility on switching magnetic fields in NMR [5] and application to MRI could be considered for research.

For the inventive problem 2, a publication was found, reporting on MRI RF coil impedance variations on respiration [6]. Human tissue is a conductive material with specific relative permittivity and conductivity. These values change with e.g. breathing and since the RF coil couples with the human tissue, the variations of the electromagnetic properties have a direct effect on the coils impedance and resonant frequency. These impedance variations can be measured

by reflected power, since a part of the transferred energy is reflected back to the source due to the imperfection. In the following volunteer experiment, we have studied this effect on cardiac motion and its application as an ECG alternative.

### 3. The MRI RF Coil as a Cardiac Sensor – Volunteer Study

#### 3.1 Measurement setup

A 75mm loop MRI coil with a resonance frequency of 64 MHz was constructed (Fig. 4a). The frequency is equivalent to the Larmor frequency at a main magnetic field strength of 1.5T. The coil was connected to a signal generator via a directional coupler (Fig. 4c). The directional coupler has two main line ports on which the RF power is transferred almost lossless, whereas two coupling ports (“Forward” and “Reflected”) provide information on the transmitted and reflected power with a defined coupling attenuation (here: -6 dB). A power sensor was connected on the reflected port. The power data of the coils was acquired and filtered with a dedicated LabView application. For synchronous data acquisition of the coil data and the ECG signal, the SAEC system [7] was used.

The data was acquired on six healthy volunteers (3 male, 3 female, age 27-36). Each volunteer was laying on the patient table of the MRI system (3T HDxt, GE Healthcare, Waukesha, WI, USA) for the whole experiment, while ECG the signals were recorded simultaneously with the coil data over 4 minutes with a breathhold at the end of the recording. The coils were placed on the lower end of the sternum (Fig. 4b). The acquired data was filtered by a second order Butterworth-Bandpass-Filter with cutoff frequencies of 0.8 Hz and 3.0 Hz. Subsequently, a simple peak detection was performed retrospectively for the ECG and coil signal on the breath-hold section of the data. The time between the R-peak of the ECG and the local minima of the coil data was measured (Fig. 5).

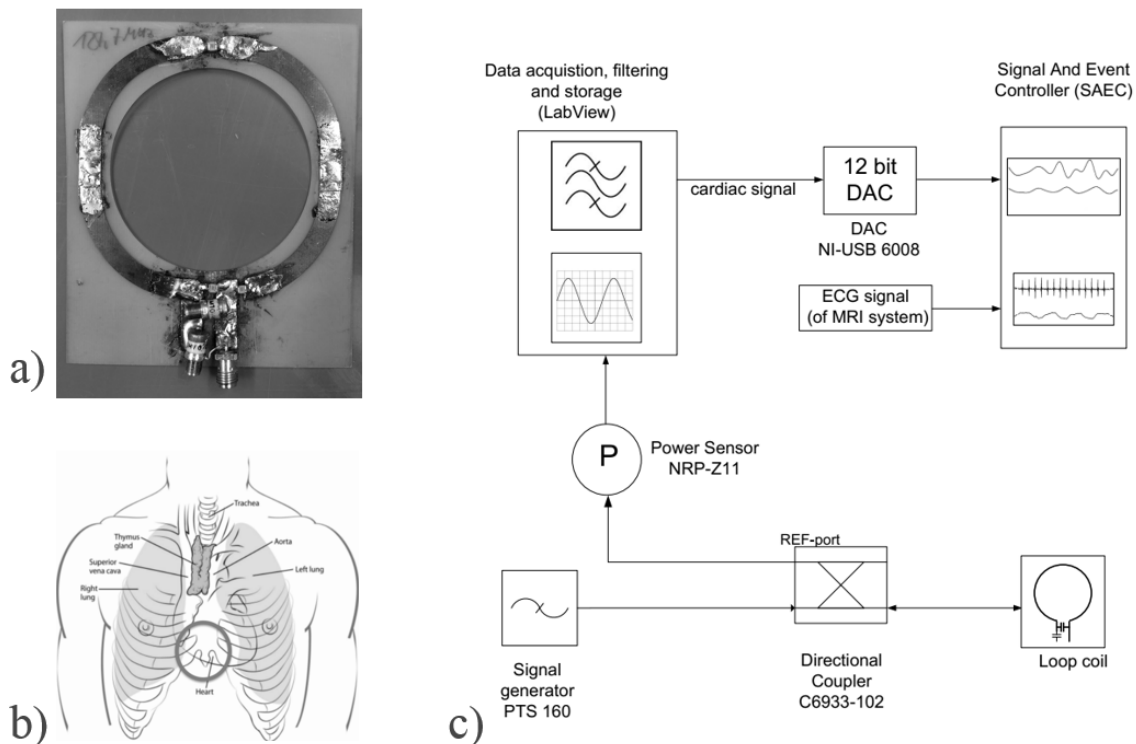


Figure 4: a) a 75mm MRI loop coil, b) the position of the coil on the volunteer, c) the measurement setup

### 3.2 Results of the volunteer study

The delay time between the R-peak and the coil data minima was found to be heart rate dependent and was between 295ms and 422ms (Table 3). This is in accordance to the time between heart contraction and the end-diastolic state, and indicates that the power signal of the coil represents blood volume variations. The standard deviation is acceptable, given that a simple peak detection was used here. More advanced filtering and peak detection algorithms might approve the accuracy. Volunteer 4 had a significantly higher variation in the delay times, which could be explained with an inadequate fixation of the coil element.

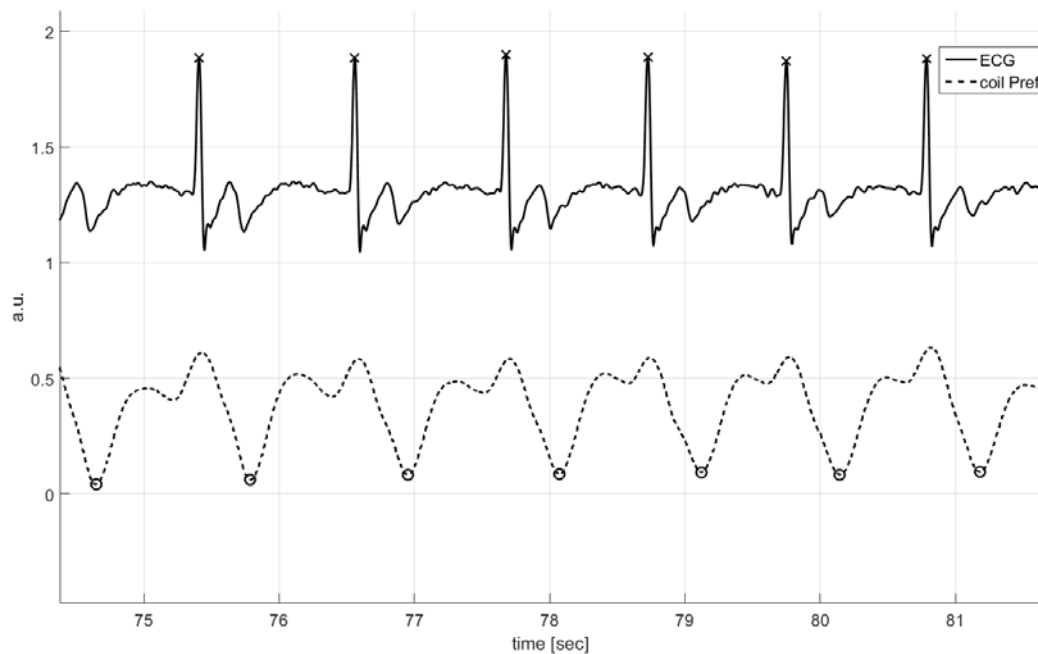


Figure 5: ECG signal (solid line) in comparison with the reflected power signal (dotted line) of the loop coil. The delay between the R-peak (x) and the power minima (°) was measured for all volunteers

Table 3

Delay time between R-peak and coil data minimum (end-diastole) for each volunteer

	delay time – mean [ms]	delay time – st.dev. [ms]
volunteer 1	383	19
volunteer 2	352	47
volunteer 3	422	11
volunteer 4	410	118
volunteer 5	295	47
volunteer 6	413	13

## 4. Conclusion

This paper discussed the criticality of the ECG-based cardiac triggering to image quality for the specific magnetic resonance imaging technique aimed to visualize the cardiac structure and the challenges that this technology poses for a correct and reliable diagnostic process. The S-Curve analysis suggested that all the explored solutions lie on the Transitional Stage, so according to the recommendations it is not advisable to pursue ideas pointing to a change of the principle of operation. This insight from the methodology helped for a successful interpretation of the outcome of the performed Function Analysis, CECA and Trimming.

By means of Trimming and the Physical Contradiction resolution two fundamental Inventive Problems were uncovered; the identified solution takes advantage of the MRI RF coil as a cardiac motion sensor and have shown its feasibility in a volunteer study. This technology was then further investigated; results emerged from a feasibility study were published in a doctoral dissertation [8] and a patent was filed [9].

The Inventive Problem 2 was not pursued by the authors; still several alternative solutions for cardiac triggering in MRI can be found in literature besides the MRI RF coil, e.g. using image information [10], cameras [11] or non-MRI RF systems [12]. One solution which detects the cardiac activity acoustically [13] can be found as a third-party product on the market. These findings confirm the validity of this approach and the power of the TRIZ methodology.

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**Communicating Author:** [kudielka@ge.com](mailto:kudielka@ge.com)

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**IDENTIFICATION AND UTILIZATION OF THE MOST  
EFFICIENT RESOURCES AMONG THOSE AVAILABLE**

Oleg Feygenson<sup>a</sup>, Naum Feygenson<sup>b</sup>

<sup>a</sup>*Samsung Electronics, Suwon, 443-742, South Korea*

<sup>b</sup>*En+ Group, Moscow, 121096, Russia*

## **Abstract**

Resource Analysis is a well-known TRIZ tool that was originally developed as a part of the Algorithm of Inventive Problem Solving (ARIZ). It is widely used as an independent TRIZ tool or in combination with some other tools (e.g., Function Analysis, Function-Oriented Search, etc.) for problem identification and idea generation.

Nowadays, many publications are available concerning resources in TRIZ. However, most of these publications describe how to reveal and classify resources, but not how to select the most suitable ones. Generally speaking, everything around us can be used as a resource for problem solving, but is there a way to select the “right” resources? What approach should we use to avoid having to test each resource one-by-one?

In this paper, we have tried to develop an approach for choosing the necessary resources directly. We propose applying the Advanced Function Approach (AFA) to develop search patterns for identifying and modifying available resources. Another aspect of the current research is the modification and utilization of different types of voidness, which is a freely available resource.

Keywords: Resources, Advanced Function Approach, Voidness.

## **1. Introduction**

The concept of resources is one of the fundamental origins of TRIZ. That is why Resources and Resource Analysis are required topics to be learned for Level 1 MATRIZ certification [1].

Resource Analysis was originally introduced as a part of the Algorithm of Inventive Problem Solving (ARIZ). The following definition is given in ARIZ-85C [2]: “Substance and Field Resources (SFR) are substances and fields that already exist or may be easily obtained according to the problem conditions.” Yet there are no practical recommendations on how to identify resources or on how to make sure a resource list includes only effective resources, while excluding unnecessary ones. This means that the processes of selecting resources and solving problems depend solely on the problem solver’s erudition and experience.

At the present time, Resource Analysis is widely used as an independent TRIZ tool or in combination with some other tools (Function Analysis, Function-Oriented Search, etc.) for problem identification and idea generation. There are some articles in TRIZ literature that contain recommendations concerning the Resource Analysis procedure. Generally, however, they are about how to identify a great number of available resources, but do not contain practical recommendations on how to select workable resources from all of those available.

The main objective of this paper is to provide a function approach for identifying resources. The general idea is to identify resources to be included in the list based on their functionality, as well as their availability in space and time. This approach has been developed through practical experience and applied in numerous innovative projects.

## 2. Literature Review

*"When I decided to select resources for solving scientific problems, I obtained a whole list of phenomena, substances and fields - from the center of the Earth to the center of the Sun"*

Voluslav Mitrofanov [3]

Many good examples of elegant solutions developed by using different resources are presented by Vladimir Urazaev [4]. In his research, Urazaev surveys patents and describes interesting examples of solving problems by using various resources.

Most publications concerning resources in TRIZ literature focus on understanding the role of resources and the identification and classification of as many resources as possible. As a result of this attention to resources, the term 'Inventive Resources' was developed in TRIZ. Boris Zlotin and Alla Zusman [5] define Inventive Resources as:

- Any substance or anything made of a substance (including waste) that is available in the system or its environment.
- An energy reserve, free time, unoccupied space, information, etc.
- The functional and technological ability to perform additional functions, including properties of substances as well as physical, chemical, geometric and other effects.

Zlotin and Zusman developed a checklist for readily available resources and suggested a way to reveal hidden resources [5].

Alexandr Gasanov gives a classification of resources and suggests an algorithm for revealing resources [6].

Sandra Mueller surveys different approaches for classifying resources both inside the field of TRIZ and in strategic management [7]. All the approaches she surveyed are used for revealing the maximum number of resources to subsequently solve a problem, either technical or in management.

Alexandr Bushuev attempts to quantitatively evaluate and compare technical and physical contradictions by employing a vector analysis of resources [8]. He evaluates the resource-intensiveness of different physical quantities and, based on these values, compares the potency of dual conflict in physical and technical contradictions.

Val Kraev, in his lessons, describes a resource approach and gives many colorful examples of resource application, specifying the features of different types of resources and ways they can be applied [9].

Gennadiy Ivanov describes an improved and more practical procedure for identifying resources in his ARIP (Algorithm of Engineering Problem Solving) [10].

Of course, there are more publications available concerning resources in TRIZ, but those mentioned above are the most complete as they summarize previous experience. Again, all these publications describe how to reveal and classify resources, but not how to select the most suitable.



Therefore, in this paper, we have tried to develop an approach on how to choose the necessary resources directly.

### **3. Advanced Function Approach for Resource Analysis**

Function Analysis, as defined in modern TRIZ, is an analytical tool that identifies functions, their characteristics, and the cost of System and Supersystem components [11]. The goal of Function Analysis is to identify disadvantages of the system such as harmful functions, insufficiently or excessively performed useful functions, and excessive cost of components. As was proposed recently, the wrong place and time for performing functions and the absence of required useful functions can also be identified using Advanced Function Approach (AFA) [12].

AFA was introduced in 2010 at the TRIZ Future Conference conducted by European TRIZ Association (ETRIA) [12]. At that time it was shown how utilizing the spatio-temporal parameters can further enhance such a powerful analytical tool as Function Analysis for Engineering Systems. Since then, AFA has proved its practical efficiency in dozens of TRIZ projects.

In this paper we propose applying AFA to identify Substance-Field resources. The suggested algorithm for evaluating resources is as follows:

1. Identify the problem to be solved.
2. Formulate a search pattern in the following format: without complicating the Engineering System and adding additional harmful effects, the X-element must [perform a function].
3. Specify the time and space where the function is needed.
4. Formulate function requirements for the potential X-element.
5. Search for the X-element as a Function Carrier inside the considered ES and its nearest supersystem. At least one of the following conditions should be satisfied:
  - The X-element already performs an identical or similar function on the Object of Function
  - The X-element already performs an identical or similar function on another object
  - The X-element performs any function on the Object of Function or, at a minimum, simply interacts with the Object of Function
6. Describe the idea(s) for the solution.
7. Identify and address the Adaptation Problems required to implement the idea.

The example below was taken from an actual consulting project which was aimed at developing a new product for moisturizing human skin, and which would identify some alternative systems for existing body lotion. One of the sub-directions here was a new delivery system for the moisturizer: a packaging and/or application procedure.

At that time, the Advanced Function Approach for Resource Analysis had not yet been formalized, yet we can see its influence at the idea generation stage.

In this project, a human's daily activities were considered as a technological process. Skin moisturizing was included as one of the operations in the process. Existing body lotion was considered to be the ES involved in the operation.

The traditional application of the lotion is to spread the lotion over the skin. The inconvenience related to such application procedure can be defined as the necessity for the consumer to perform additional actions.

So, we have a problem: how to apply lotion all over the body's skin without additional actions by the consumer?

The search pattern would be: without complicating the Engineering System and adding additional harmful effects, the X-element must deliver lotion all over the skin.

Time and space would be specified as follows: time – anytime where access to human skin exists; space – upper skin layer.

Function requirements for the X-element were stated as follows: "amount of additional actions required from the consumer" and "skin surface area processed per time unit."

All ESs involved in the human daily activity process were considered to be supersystem components and potential X-elements (see Figure 1).

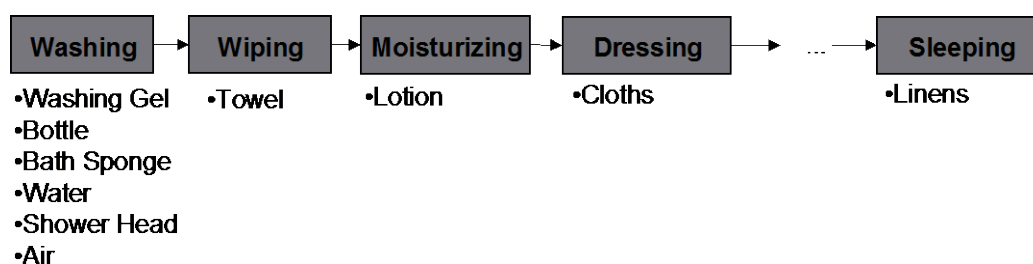


Figure 1. Identifying possible resources for moisturizing human skin

A number of supersystem components were recommended as a potential delivery system for a moisturizing product. For instance, shower gel, water and shower head can be components at the washing stage; a towel can be a component at the wiping stage, bed linens can be a component at the sleeping stage, etc.

What is important here is that we did not list and classify all possible resources; instead, we were focused only on the resources with the required functionality.

## 4. Application of Void

As is mentioned in Part #4 of ARIZ, void is an important resource which is always available, cheap and can be mixed with substances. However, the function of void cannot be formulated since it is not a material object.

This is why we recommend that void is necessarily checked as a possible resource. When AFA is applied, void may be interpreted in different ways: void as an empty space or void as a time interval in which no functions are performed.

A good example of utilizing void to develop a new conceptual design for an electric machine is shown in [13]. It should be noted that when we analyse and improve simple ESs, the ideas and final solutions are hard to find because of the absence of system resources. Often, in such situations void is a perfect resource, as shown with the example below (see Figure 2).

The problem is: how to lock a nut in place permanently? The nut should be tightened and stay in place. No additional components (e.g., nut lockers) can be added. In such a situation, there are not many resources. However, void is always available. The idea for permanently affixing a nut is as follows: a cut is introduced on the side surface of the nut (as shown in Figure 2) and when the nut is fastened in place, a hammer can be used to hit and compress the nut, which will damage the nut's thread and, thus, it will be impossible to dislodge the nut.

As mentioned in [14], void allows an object to increase the number of functions it can perform. When void is utilized, it resolves the following contradiction: additional components should be added to the system in order to increase the number of its functions, but the additional components should not be added in order to keep the system cheap and simple. Void does not add any cost or complexity to a system.

In the same research [14] practical recommendations on how to introduce void to different objects can be found.

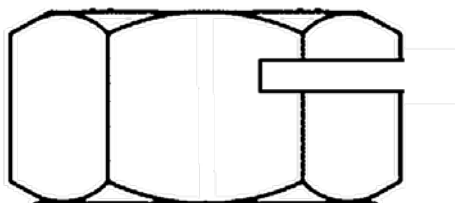


Figure 2. A nut which locks itself

## 5. Conclusions

Here we have combined and verbalized an approach that could be used for solving inventive problems by searching and evaluating resources. The main idea behind the approach proposed is that we need first to understand what function is required from a resource, where and when it is required, and then we will be able to identify the most suitable resource among the many available. In another aspect of the described approach we use void as a resource in a systematic way. It is not possible to identify void itself using functional criteria since void is not a material object. However, as demonstrated above, it is possible to add void to the other objects and increase their functionality.

## Acknowledgements

We extend our sincere thanks to all authors and TRIZ developers who are mentioned in the references for revealing the importance of resources in modern TRIZ and developing some approaches for classifying resources. Special thanks to Deborah Abramova who helped to make this paper sound literate in English.

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**Communicating Author:** [oleg.feygenson@gmail.com](mailto:oleg.feygenson@gmail.com)

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**IDENTIFYING KEY PROBLEMS AND CONCEPTUAL DIRECTIONS USING THE ANALYTICAL TOOLS OF MODERN TRIZ**

Oleg Y. Abramov<sup>a</sup>, Stéphane Savelli<sup>b</sup>

<sup>a</sup>*Algorithm Ltd., 16 Ruzovskaya Street, St. Petersburg, 190013, Russia*

<sup>b</sup>*MP Solving, Rue Copernic 48, 1180 Brussels, Belgium*

**Abstract**

The analytical tools of modern TRIZ are applied to the innovation of products, processes or services to reveal numerous disadvantages that impede the innovation goal. Each of these disadvantages can then easily be converted into a problem aimed at eliminating the disadvantage, making it possible to solve the problem with any of the TRIZ problem solving tools. However, because modern TRIZ tools, such as Cause-and-Effect Chain Analysis (CECA), usually reveal dozens to hundreds of disadvantages, it is impractical to eliminate all revealed disadvantages, that is, to solve all problems. Therefore, it is important to identify and solve only the most promising disadvantages and corresponding problems (further: Key Disadvantages and Key Problems) whose solutions maximize the expected value of the innovation project at hand. This is not an easy task, however, and modern TRIZ has not yet developed well-defined recommendations on how to identify Key Disadvantages and Key Problems. In this paper, the authors try to fill this gap by proposing (1) a Cause-and-Effect Chain topology-based approach for identifying Key Disadvantages and Key Problems, (2) recommendations for grouping these Key Problems into Conceptual Directions based on the topology of the Cause-and-Effect Chains, and (3) recommendations for including into Key Problems some problems revealed by non-CECA analytical tools as, for example, Feature Transfer, Trends of Engineering Systems Evolution (TESE) and Trimming.

Keywords: CECA, conceptual directions, key disadvantages, key problems, TRIZ

**1. Introduction**

Modern TRIZ analytical tools such as Function Analysis, Trend of Engineering Systems Evolution (TESE) analysis and Cause-and-Effect Chain Analysis (CECA) normally reveal numerous disadvantages that impede eliminating the target disadvantage and achieving the innovation goal. Each of these disadvantages can easily be converted into a problem aimed at eliminating the disadvantage, after which TRIZ problem solving tools may be applied to solve the problem.

Many researchers suggest solving all of the revealed problems first, and then selecting the best solution for further implementation. For example, Pinyayev in his conference paper [1] clearly formulated this tactic: “My approach is to break the initial inventive situation down to a multitude of problems and solving most if not all of them.” Indeed, this approach yields good results, but it is not always practical because the number of identified problems in many cases is too large (dozens to hundreds) to solve all of them within a reasonable timeframe.

Therefore, it is important to identify and solve only a few of the most promising disadvantages and corresponding problems (further: Key Disadvantages and Key Problems) whose solutions maximize the expected value of the innovation project at hand. This is not an easy task, however, and modern TRIZ has not yet developed well-defined recommendations on how to single out Key Dis-

advantages and Key Problems from the numerous disadvantages and problems revealed by the analytical tools of modern TRIZ.

Nevertheless, a few attempts to develop such recommendations have been made by TRIZ developers. In Efimov's online publication [2], the criteria previously suggested by various researchers for identifying Key Disadvantages are reviewed and discussed. These criteria are:

- The method for eliminating the disadvantage is known or obvious;
- Potential solutions eliminating the disadvantage provide the biggest profit and highest novelty, require the smallest changes in the engineering system at hand, can be implemented with just the system's internal resources, and meet all constraints implied in the project;
- The disadvantage is located closer to the root disadvantages in the cause-effect chain, and, therefore has the highest weight, evaluated as the number of intermediate disadvantages located on the same branch of the cause-effect chain;
- The disadvantage represents a hub in the cause-effect chain in which several branches of the chain converges or diverges.

In his paper, Efimov has shown that none of these criteria is ideal because some of them are difficult to evaluate in real life, while others are not reliable enough. For example, before actually having a solution, it is difficult to estimate whether that solution will be easy to implement, be profitable and meet all the imposed constraints. So, Efimov suggested another criterion: Key Disadvantages are those that relate to technical or physical contradictions in the system. Unfortunately, even this criterion has a drawback: practice shows that a disadvantage transformed into a functional problem can lead to valuable solutions by using a Function-Oriented Search, even though the disadvantage does not relate to a contradiction.

In order to make the identification of Key Disadvantages easier, Pavlov in his conference paper [3] suggested simplifying cause-effect chains by eliminating intermediate disadvantages located on the same branch of the chain, which also allows building a map of Key Problems. Later, Chrzęszcz and Salata [4] proposed a more comprehensive approach for minimizing cause-effect chains using methods employed in Boolean algebra, but the authors admitted significant limitations in the applicability of this method to CECA.

Chrzęszcz and Salata [4] also suggested a method for evaluating the impact of CECA-revealed disadvantages based on the number of target disadvantages affected by a particular disadvantage in the cause-effect chain. Recently, Chrzęszcz [5] developed a more advanced quantitative approach to CECA that assumes the selection of Key Disadvantages based on their profitability, which is mainly based on the ratio of expected profit from the elimination of the disadvantage to the cost of its elimination. The latter, however, is difficult to estimate in advance, before the solution is found and implemented, which makes it difficult to use this approach in practice.

In order to accelerate the implementation of a TRIZ project, Savelli [6] suggested omitting some conceptual directions (CDs) after formulating all of the Key Problems. He gave an example of selecting the most promising CDs, but did not provide recommendations on how to identify them systematically. Moreover, he did not specify an algorithm for identifying CDs in general.

It should be noted that all existing methods for identifying Key Disadvantages and Key Problems work only for CECA-revealed disadvantages, while CECA is just one of a few analyses in modern TRIZ that contributes to Key Disadvantages and Key Problems. The others are Trimming, which is considered a part of Function Analysis, Feature Transfer and TESE analysis. All of these may yield problems outside the scope of CECA; for instance:

- If a component of an Engineering System (ES), which is a promising candidate to trim, does not have a functional disadvantage influencing the target disadvantage, it will not appear in CECA;
- If an identified TESE disadvantage relates to the absence of an important part of the ES, the absent part and related disadvantages will never appear in CECA;
- Feature Transfer problems do not normally appear in CECA because CECA is typically applied to the ES that wins in TRIZ Benchmarking, but since Feature Transfer always focuses on two ESs with opposite advantages and disadvantages, at least one of these ESs will not be included in CECA.

Therefore, the innovation roadmap of modern TRIZ [7] should include not only CECA problems, but also Trimming, Feature Transfer and TESE problems as the inputs for Key Problem Formulation (see Fig. 1).

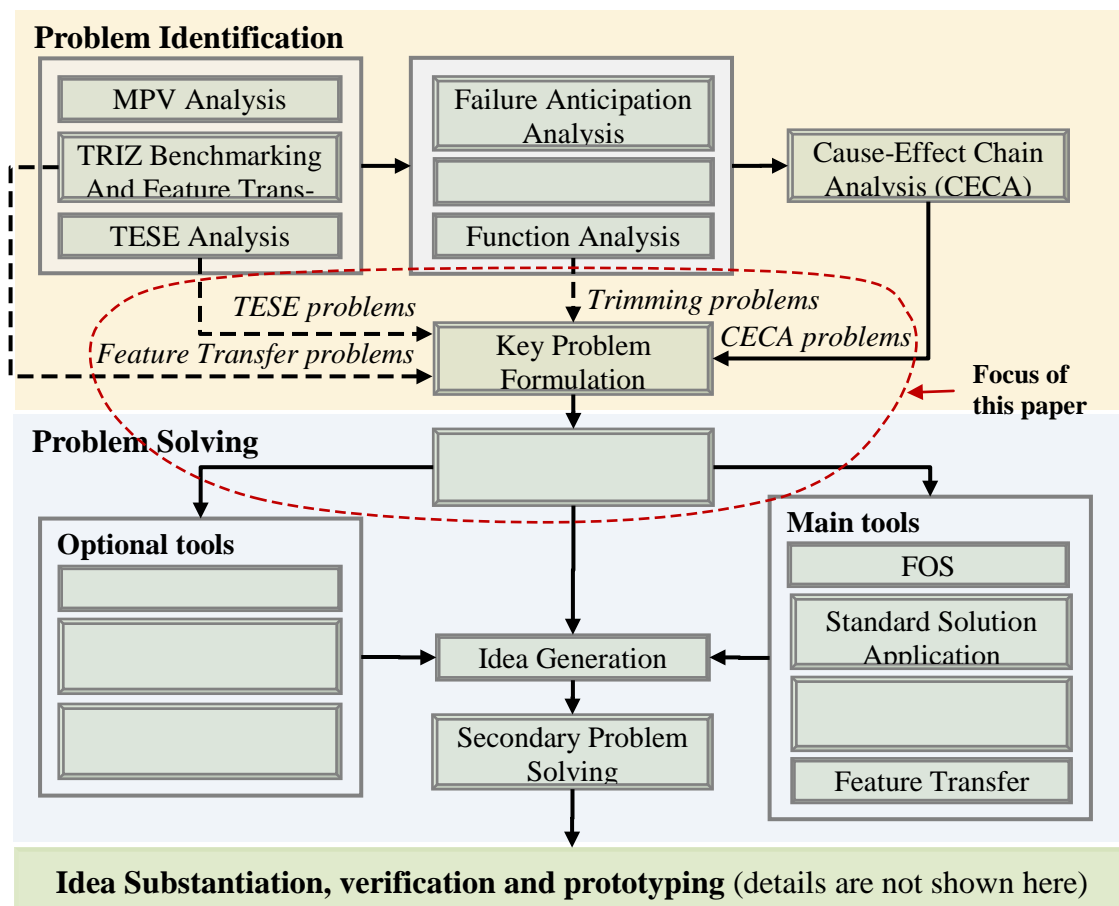


Fig. 1. Innovation roadmap of modern TRIZ [7]; the focus of this paper

In this paper, the authors provide recommendations for identifying the Key Problems in the entire pool of problems revealed at the Problem Identification stage (including TESE, Feature Transfer, CECA and Trimming problems seen in Fig. 1). Additionally, in order to reduce the number of Key Problems to be solved, the authors provide recommendations for identifying the most promising Conceptual Directions (CDs) in which the Key Problems are worth solving.

## 2. Method

The authors propose modifying the innovation roadmap shown in Fig. 1 so that Conceptual Directions are first developed and then screened in order to reject those that have low business or technical potential. This automatically eliminates the Key Disadvantages and corresponding Key Problems related to the rejected CDs, thus reducing the total number of Key Problems to be solved.

A Conceptual Direction, as understood here, is a group/subset of Key Disadvantages and related Key Problems that when solved together (and only together) eliminate the target problem. (Each CD is normally assigned a name that concisely expresses its nature.)

In order to minimize the number of Key Problems, this research uses the following methods and tools:

- Analysis of the cause-effect-chain topology. The chains should be built using CECA, as previously described by Abramov [8]. This is used to identify CECA-derived CDs that correspond to individual branches of the cause-effect chain.
- The recently proposed QEA-based (Quantum Economic Analysis) screening [9], which allows evaluating the business potential of individual Conceptual Directions. (Business potential is understood here as the client's ability to commercialize solutions that relate to these CDs.) The directions with low business potential are excluded from further consideration and no disadvantages or problems related to these CDs should be considered Key Disadvantages.
- S-curve analysis [10-11]. This is used to identify which revealed TESE and Trimming problems need to be addressed urgently and, hence, should be treated as Key Problems.

## 3. Results

A fragment of the modified innovation roadmap is shown in Fig. 2. As can be seen from Fig. 2, the authors propose (1) swapping CD Development and Key Problem Formulation steps, and (2) introducing CD and Key Disadvantage Screening between these steps.

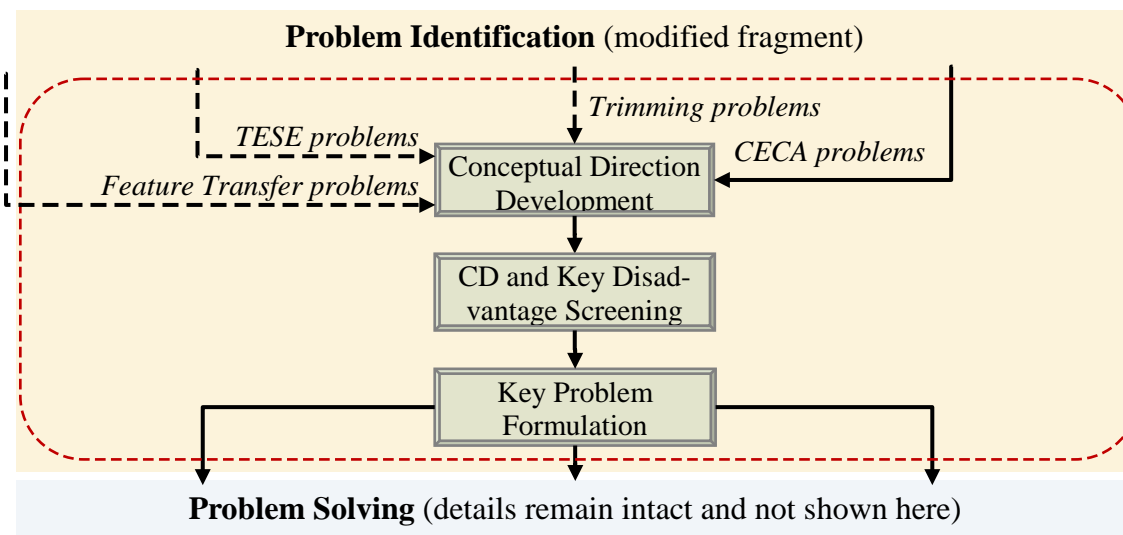


Fig. 2. Modified fragment of the innovation roadmap

Screening the Conceptual Directions efficiently reduces the number of CDs and corresponding Key Disadvantages by rejecting those CDs that are unpromising TESE-wise and/or have low business potential. As a result, far fewer Key Problems are formulated, which (1) saves the effort and



time required to eliminate the target problem, and (2) reduces the risk of developing impractical solutions that will unlikely be profitable for the client.

Details of the innovation roadmap steps shown in Fig. 2 are explained below.

### *3.1. Conceptual Direction Development based on cause-effect chain topology*

In this paper, we assume that cause-effect chains are complete and have been built using CECA [8] all the way down to the root causes that, for various reasons, cannot be eliminated.

As shown in Fig. 3, CDs are formed differently depending on the cause-effect chain topology:

- In the purely ‘conjunctive’ chain that contains only ‘AND’ gates, each CD will include one Key Disadvantage (and, hence, one Key Problem) located in the end of the chain - right next to the root cause. Eliminating any Key Disadvantage is enough to solve the target problem. There may be as many CDs as there are branches in the chain ( $N$  in Fig. 3a).
- In the ‘disjunctive’ chain that contains only ‘OR’ gates (Fig. 3b), there will be only one CD that includes all the Key Disadvantages, which must be eliminated together in order to solve the target problem.

If a cause-effect chain contains both ‘AND’ and ‘OR’ gates (Fig. 3c), then the number of CDs may vary depending on the particular topology of the chain. CDs that relate to the branches of the chain containing only ‘AND’ gates will include just one Key Disadvantage; other CDs may include several Key Disadvantages that must be eliminated together.

Generally, in order to identify CECA CDs, it is necessary to identify all minimum subsets of Key Disadvantages, which must be eliminated together in order to solve the target problem.

The Key Disadvantages, as shown in Fig. 3, are normally located in the end of a cause-effect chain (next to the root causes). If, at the problem solving stage of the project, some of the Key Disadvantages are too difficult to eliminate, they may be substituted by an upper-level disadvantage from the same branch of the cause-effect chain.

### *3.2. Conceptual Direction Development for Trimming, TESE and Feature Transfer problems*

Trimming is normally applied to one or several components of the ES that presents functional or cost disadvantages. The output of Trimming consists of one or several Trimming Problems.

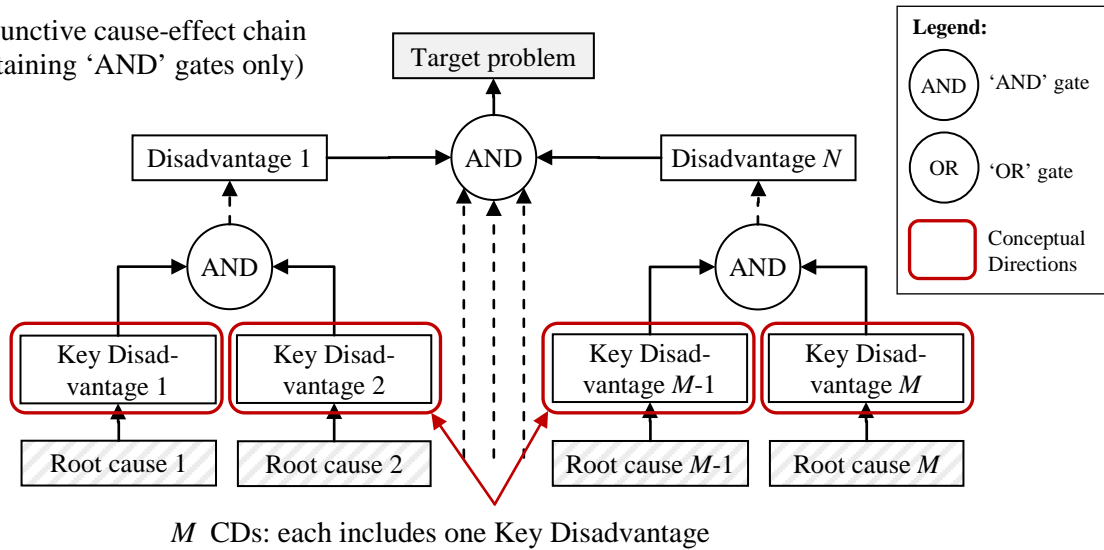
In a typical Trimming Problem, the trimming of component  $I$  is expressed as follows: how can component  $J$  fulfil function  $F$ ? (Here function  $F$  is a useful function that has been eliminated with trimmed component  $I$ .) This Trimming Problem can be considered a Key Problem, or it can be further analyzed using a separate CECA in order to reveal underlying Trimming Problems. In the latter case the target disadvantage of CECA would be: ‘component  $J$  doesn’t fulfil function  $F$ ’.

In practice, all Trimming Problems related to the Trimming of one component are normally grouped into a single conceptual direction, thus forming a specific Trimming CD.

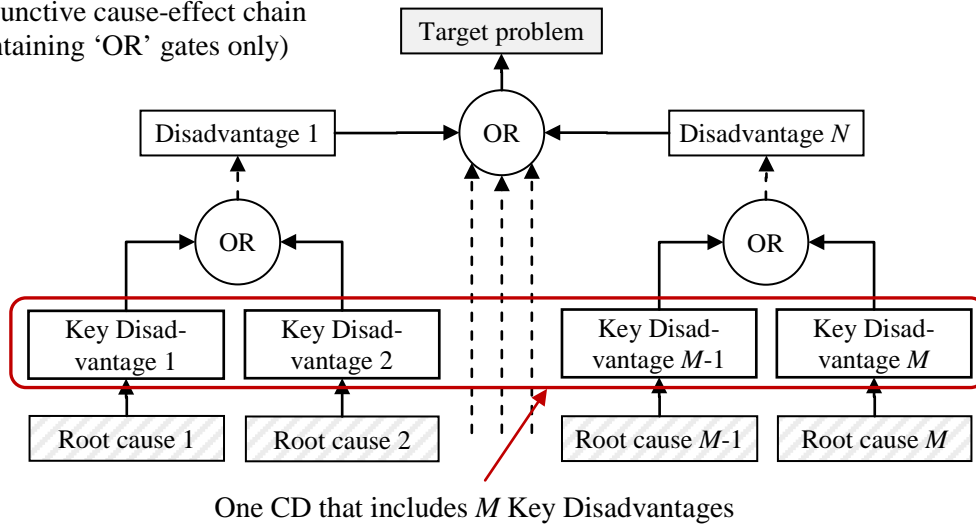
As with Trimming, TESE can be applied to one or several components of the ES; but the components this time are those that may most benefit from a technological evolution. The output of TESE typically consists of one or more TESE Problems, which can be considered Key Problems, or a separate CECA can be applied to the component(s) in order to reveal underlying TESE Problems. In all cases, different Problems can be grouped into TESE CDs. Usually, one TESE CD includes all TESE Problems related to a specific component.

In the same way, identified Feature Transfer (FT) Problems can be grouped into FT CDs.

a) Conjunctive cause-effect chain  
(containing 'AND' gates only)



b) Disjunctive cause-effect chain  
(containing 'OR' gates only)



c) Mixed cause-effect chain (containing both - 'AND' and 'OR' gates)

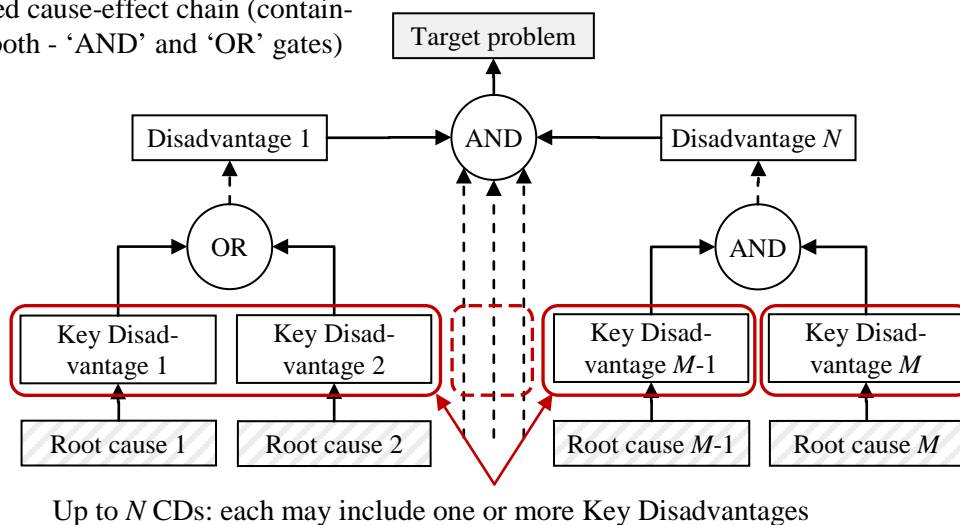


Fig. 3. Conceptual Directions for different cause-effect chain topologies (simplified representation)

### 3.3. Conceptual Direction Screening

After Conceptual Directions have been developed, they can be presented in the form of a table. For example, the CDs developed for the cause-effect chain shown in Fig. 3c are shown in Table 1.

Table 1

Conceptual Directions for the cause-effect chain shown in Fig. 3c

CD #	CD name	Key Disadvantages (KD) to solve	Priority/Importance
1	CD <sub>1</sub> name	KD <sub>1</sub> ; KD <sub>2</sub>	To be determined by screening
...	...	...	...
...	CD <sub>N-1</sub> name	KD <sub>M-1</sub>	To be determined by screening
N	CD <sub>N</sub> name	KD <sub>M</sub>	To be determined by screening

The goal of CD screening is to identify which, if any, Conceptual Directions are unimportant and, therefore, can be rejected, or at least considered low priority, and be pursued only if more promising CDs do not yield a good solution for the target problem.

The authors suggest evaluating a CD's importance using two criteria:

1. The technical relevance of the CD to the engineering system (ES) at hand. This means that a CD is considered unimportant if it clearly suggests changes in the ES that are not of highest priority at the current stage of the ES evolution. For example, if the ES is currently at the 1<sup>st</sup> or 2<sup>nd</sup> stage of evolution, then all CDs involving cost reduction, trimming components or changing the ES's action principle should be rejected because they do not meet the Voice of the Product (VOP), i.e. the "voice of the ES".
2. The business potential of the CD. This means that those CDs that the client (problem owner) will be unable to implement and monetize should be rejected too. For example, if the client is a large company that sells a mature product on a well-developed market, then all CDs suggesting breakthrough solutions/products that do not have a developed market yet, should be rejected because a large company will unlikely be able to commercialize such solutions.

The technical relevance of the CDs can be evaluated using a well-developed TESE analysis [10, 11] and VOP approach, as explained by Abramov in a previous conference paper [12].

The business potential can be evaluated using QEA-based screening [9], which is a new TRIZ tool and less known to TRIZ practitioners. The tool uses the following fragments of the original QEA [13]:

- Identification of the levels of development for the company, its product and target market – see Table 2 for the characteristics of each level;
- The specific combinations of these levels that allow a business to be successful (further referred to as Allowed Set). The allowed set is shown in Fig. 4.

QEA-based screening involves (1) identifying what the combined levels of development for the company, its product and target market will be if a Key Disadvantage/Key Problem is eliminated, and (2) checking whether this combination falls into the Allowed Set in Fig. 4. A Conceptual Di-

rection is considered unpromising if the elimination of any related Key Disadvantages/Key Problems yields a combination that does not fall into the Allowed Set.

Table 2

Characteristics of product, company and target market levels of development [9]

Level of development	Development level characteristics		
	Product (P)	Company (C)	Market (M)
0	N/A	N/A	Very few consumers - early adopters only
1	Product level of development is determined as in regular TRIZ S-curve analysis, e.g. as described by Litvin and Lyubomirskiy [11]	Company can access up to \$3M in capital	New consumers appear, but they keep using previous product as well
2		Company can access from \$10M to \$100M in capital	Mass consumer is switching to the new product, abandoning previous
3		Company can access over \$100M in capital	All potential consumers are already using new product
4		N/A	Consumers are leaving the market and switching to a newer product

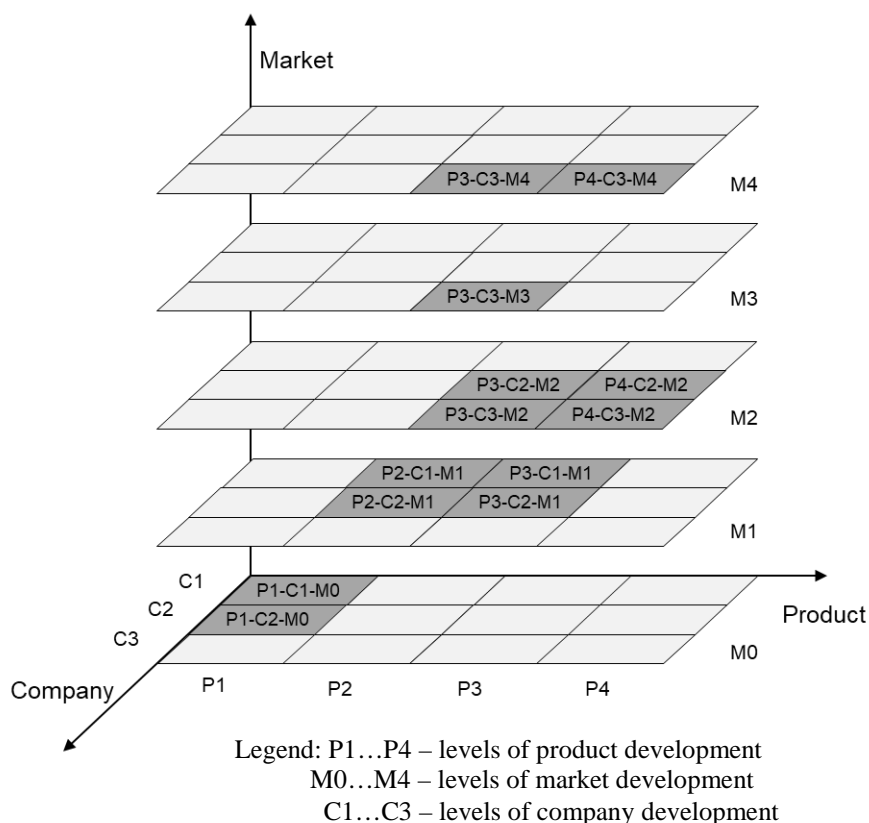


Fig. 4. The Allowed Set in the QEA Business Cube (see dark grey cells) [13]

QEA-based screening applied to other objects of improvement, for example to production technologies, is described in the original paper [9].

### 3.4. Key Problem Formulation

CECA-derived Key Disadvantages for the CDs that have survived the screening can easily be converted into Key Problems (KP) this way: ‘ $KP_n$  = how to eliminate  $KD_n$ ’, where  $KD_n$  is Key Disadvantage number  $n$ .

In Trimming, KDs reflect the fact that the remaining components do not perform a function previously performed by a trimmed component, and in TESE, they do not meet TESE. These KDs can be converted into KPs the same way as described above for CECA.

Feature Transfer problems occur when no benchmarked technology fulfils all requirements and two benchmarked technologies have opposite advantages and disadvantages. Therefore, FT-derived KPs are typically formulated this way: how to make an ES that combines the advantages of the two benchmarked ESs while excluding their disadvantages?

After formulating all of the Key Problems, it is necessary to analyse whether some KPs within the same CD require opposite changes in the physical parameters of the component or its action. If yes, such KPs should be combined into a single KP that is expressed as a contradiction.

## 4. Case studies illustrating the proposed approach and procedures involved

### 4.1. Case study 1. Hammer drill

This case study relates to the problem of drilling hollow bricks with a rotary hammer drill designed to drill concrete. The problem was that the drill’s impact energy was too high and damaged the brick. More details on the target problem can be found in the conference paper on CECA [8].

The client in this case was a large company that produced and sold hammer drills in a well-developed market. In terms of QEA, the company, the market and the product (hammer drill) were at the 3<sup>rd</sup> level of development (cell P3-C3-M3 in the QEA business cube in Fig. 4).

Fig. 5 represents a cause-effect chain of the target problem, simplified slightly from that given in the previous paper [8].

This chain, in Fig. 5, contains only ‘AND’ gates and, therefore, three revealed Key Disadvantages form three separate Conceptual Directions as shown in Table 3.

Table 3

Conceptual Directions for the cause-effect chain shown in Fig. 5

CD #	CD name	Key Disadvantages (KD) to solve	Priority/Importance
1	‘Controllable impact energy’	Rotary hammer’s impact energy is too high (for a brick)	Important; high priority
2	‘Controllable impact duration’	Impact duration is too short (for a brick)	Important; high priority
3	‘Hypersonic drilling’	Drill bit’s penetration speed in the brick is too low	Unimportant for the client; low priority

The conceptual directions (see Table 3) identified from the CECA topology shown in Fig. 5 are:

1. ‘*Controllable impact energy*’ that assumes reducing the impact energy if a brick is being drilled. The Key Problem to be solved in this CD is: how to reduce impact energy when drilling a brick?

2. ‘*Controllable impact duration*’, which suggests increasing the duration of impact when drilling bricks, while keeping the impact energy unchanged. The Key Problem in this CD is: how to increase the duration of impact when drilling a brick?
3. ‘*Hypersonic drilling*’ assumes dramatically increasing drill bit penetration speed so as to make it faster than the speed of crack propagation in the brick (~3600 m/sec). The key problem is: how to increase the drill bit velocity to hypersonic speed?

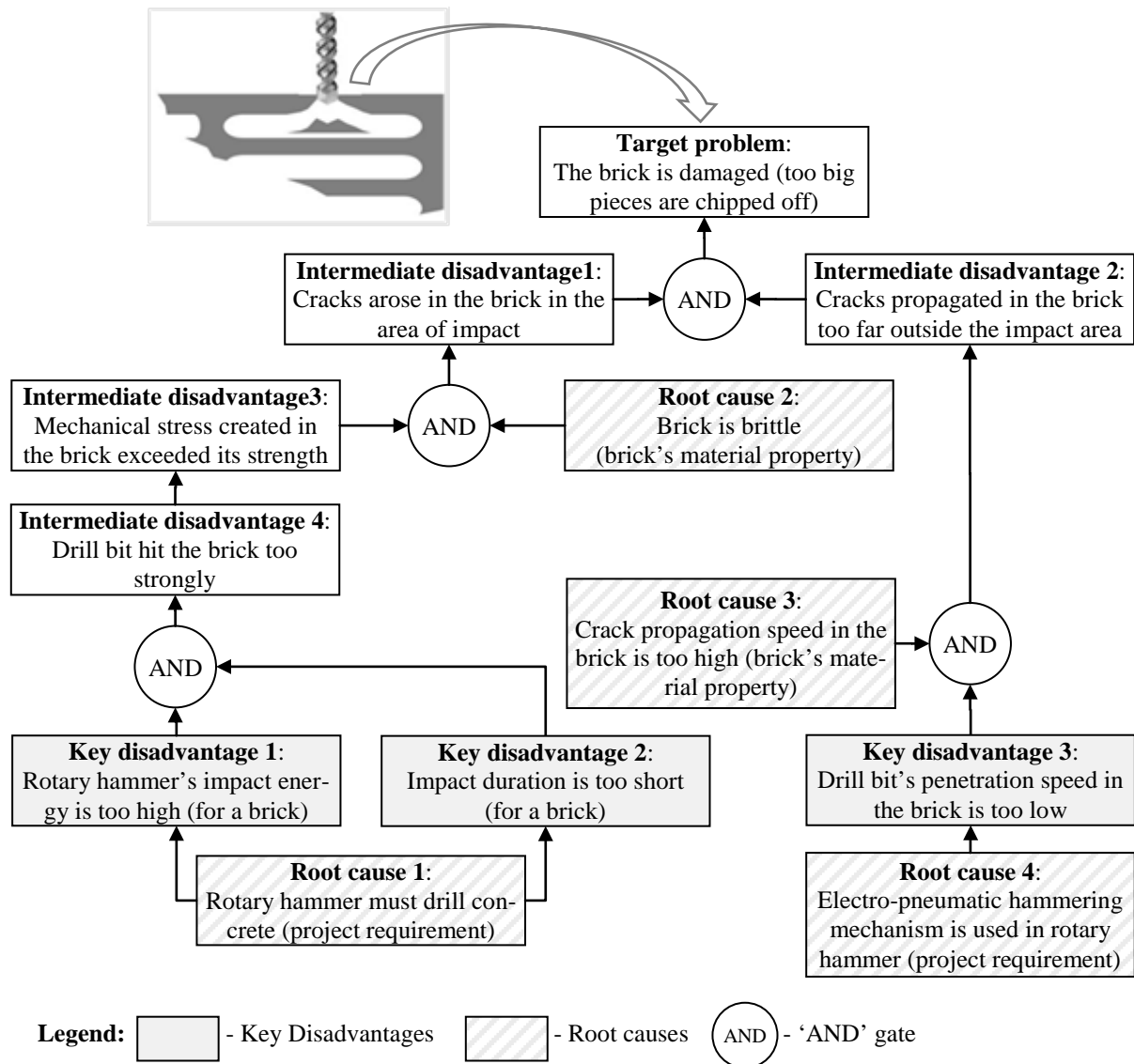


Fig. 5. CECA of the rotary hammer drill target problem

The screening of these CDs yielded the following results: solutions for CD1 or CD2 do not necessarily require changing the action principle of the hammer drill, while solutions for CD3 will definitely involve developing a drill with a completely new action principle.

This means that solutions for CD1 and CD2 will likely yield a drill that is at the 3<sup>rd</sup> stage of evolution – just like the existing drill.

Also, in terms of the QEA business cube, the combination of the Product, Company and Market levels of development will not change (cell P3-C3-M3 in Fig. 4). So, these solutions are expected to be safe businesswise.

Any solution for CD3, however, will yield a brand new product that is at the 1<sup>st</sup> stage of its evolution, while the company and the market will remain at the 3<sup>rd</sup> stage of development. In the business cube, this situation will fall into the cell P1-C3-M3, which is outside the Allowed Set (Fig. 4). This means that the client will unlikely be able to commercialize solutions for CD3.

Based on these considerations, we estimated the importance of all three CDs in Table 3, which indicates that CD1 and CD2 have high priority and, therefore, should be taken for further development, while CD3 has low priority and should be rejected.

#### 4.2. Case study 2. Laser printer

This is a ‘virtual case study’ created using the information available in the public domain.

The laser printer is a very common product that consumes relatively expensive toner to print. Imagine a start-up company whose objective is to launch a laser printer with reduced toner consumption.

Following the innovation roadmap of modern TRIZ in Fig. 1, the start-up team could perform CECA, similar to that in Fig. 5, in order to identify Key Disadvantages responsible for high toner consumption in the printer. Without going into detail, one can anticipate that several CDs will emerge from this CECA, which could be divided into two groups:

1. CDs that will yield an improved laser printer with reduced toner consumption at the 3<sup>rd</sup> stage of evolution, just like the existing printer. In the QEA business cube (Fig. 4), these CDs will yield solutions corresponding to cell P3-C1-M3, which is outside the Allowed Set. Therefore, the start-up must reject these CDs because it cannot compete in the existing laser printer market with big companies also working on improvements.
2. CDs that will yield a brand new printer at a stage of evolution earlier than that of the existing printer. This product does not yet have a market and solutions from these CDs will fall into cell P1-C1-M0, which is in the Allowed Set in Fig. 4. Therefore, these CDs are of highest priority for the start-up.

An example of the second group might be to create a new printer by trimming the toner, which is obviously a component that has functional and/or cost disadvantages directly related to the project’s objective. One component of the printer that has resources to fulfill the function of toner is the laser, and the initial Trimming Problem to solve would be ‘How can the laser create a print?’

Certainly, a laser that is powerful enough can carbonize paper, thus creating a print, but there will be another disadvantage, or secondary problem: the laser can burn the printing paper. So the initial Trimming Problem will transform into ‘How to control the laser carbonization of regular paper?’ This is what the company should focus its R&D efforts on. This Trimming Problem yields a Trimming CD, which could be called ‘monochrome laser printing without consumables’.

In reality, the Dutch start-up company Tocano (spin-off of TU Delft) has developed such a technology, called Inkless®, based on a pulsed, infra-red laser [14,15].

From a methodological point of view, we could apply TESE to the laser printer and would obtain a TESE Problem ‘How to print using only field(s)?’ Since the current printing process utilizes several fields (light field, electrostatic field, and temperature field) and a substance (toner), this TESE problem is, in fact, equivalent to the Trimming Problem described above. Interestingly, the TESE approach would yield exactly the same CD as the Trimming CD.

#### 4.3. Case study 3. Slow-blunting knife

This is another ‘virtual case study’ created using the information available in the public domain.

The kitchen knife is a very common product. Imagine a company (with access of up to \$100M in capital) that is well established and whose market is stainless steel kitchen knives. Its objective is to launch a stainless steel kitchen knife which blunts very slowly. The target consumers for this product are restaurant kitchen professionals, who need to sharpen their knives very often.

Following the innovation roadmap of modern TRIZ in Fig. 1, the company could perform TRIZ Benchmarking, which would yield two types of knives already on the market that have opposite advantages and disadvantages: (1) a stainless steel knife, which doesn't break easily but blunts quickly; and (2) a ceramic knife, which blunts slowly, but breaks easily.

By applying Feature Transfer to these two products, we can formulate the Feature Transfer problem: 'How to transfer the slow blunting of the ceramic knife to the stainless steel knife while preserving its high breaking-resistance?' This FT problem yields an FT CD that could be called 'Ceramic-like stainless steel knife'. Solutions for this CD will represent a breakthrough knife that will fall into cell P1-C2-M0 in the QEA business cube (Fig. 4). This cell is within the Allowed Set, and, therefore, the company should give this CD high priority and focus its R&D effort in this direction.

This is, in fact, what the French company Tarrerias Bonjean did in their development of the Evercut® knife [16]. The edge of this knife is made of a composite alloy of stainless steel and very hard ceramic powder through laser powder sintering [17]. It blunts 300 times slower than a usual stainless steel kitchen knife.

Similarly to the previous case-study, CECA could be performed in order to identify Key Disadvantages responsible for the fast blunting of a stainless steel knife. It would probably yield a group of CDs aimed at increasing the hardness of stainless steel. These CDs will result in an improved kitchen knife that is at the 3<sup>rd</sup> stage of evolution, just like the existing knife. In the QEA business cube, these solutions will fall into cell P3-C2-M3, which is outside the allowed set. Therefore the company should reject these CDs and not invest in developing solutions for them.

## Conclusions

In this paper, we show how to apply the modern TRIZ innovation roadmap to identify Conceptual Directions and corresponding Key Disadvantages / Key Problems revealed by CECA, Trimming, TESE analysis and Feature Transfer.

Also, we suggest screening the identified conceptual directions first in order to immediately reject those that are unpromising business-wise without investing any development efforts into them. The screening constitutes a new, intermediate step in the modern TRIZ innovation roadmap.

QEA-based screening (a new TRIZ tool not yet well-known to TRIZ practitioners) is proposed as an appropriate tool for this step.

The effectiveness of the proposed approach is illustrated by three case studies.

## Acknowledgements

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**Communicating Author:** Oleg.Abramov@algo-spb.com

**TRIZfest 2018**  
**September 13-15, 2018. Lisbon, Portugal**

**PARADIGMING**  
**TRIZ AS DESIGN FRAMES IN PHILOSOPHY EDUCATION**

Ruud Heesen<sup>a</sup> and Christoph Dobrusskin<sup>b</sup>

<sup>a</sup> *Varendonck College, Asten, The Netherlands*

<sup>b</sup> *Royal Philips, Eindhoven, The Netherlands*

**Abstract**

Inspired by TRIZ as promoted by Royal Philips, by Design Thinking for education and Frame Innovation principles, we developed a social design project: “paradigming”, whereby the inventive TRIZ-principles are applied as design Frames in philosophy education. Our question is: How and why does TRIZ “work” in education? In this project 11<sup>th</sup> grade students, either individually or in pairs, need to apply the inventive TRIZ-principles, design by framing and philosophy knowledge to design an innovative project. The present paper presents our approach and provisional results.

Keywords: Philosophy education, TRIZ, Frame Innovation, Design Thinking, Paradigming, Social Design, Educational projects, Students, Netherlands

**1. The Framework**

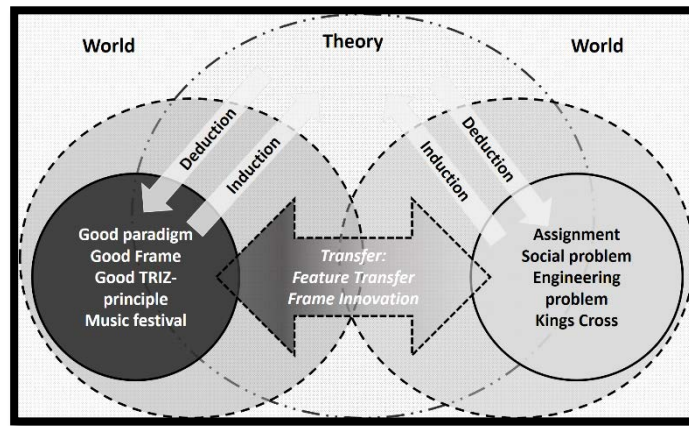
*1.1. How and Why*

*How and why* does TRIZ, the Theory of Inventive Problem solving, “work” in education? This is an important question, since TRIZ is proposed as tool to accelerate critical thinking, problem-solving skills and creative thinking, all part of the so-called 21<sup>st</sup> century skills promoted in education [12]; these are skills used to deal with complex problems. The starting point is the application of *TRIZ* – and we focus on its mindset, the inventive principles, and implicitly on feature transfer and resource analysis – to *non-engineering problems*, like social design problems. Understanding how and why TRIZ “works” in education could open up *spin offs and new insights* for engineers and teachers.

Figure 1 should be considered a map to orientate the reader, while reading the article.

- The closed right hand circle represents a normal project situation such as an assignment in class, in our case a normal social problem like Kings Cross [13]. ‘Normal’ means that one tries to ‘solve’ the problem by means of induction and deduction. – A chemistry example: Calculate how many liters of carbon dioxide are produced by the combusting one liter of petrol. By *inducing* the assignment to chemical calculation *theory* and using its formulae, a student can *deduce* the answer.
- The closed left hand circle represents a paradigm, a good Frame like a music festival [13], or a good TRIZ-principle. The present paper discusses in how far learning and designing by means of good paradigms, Frames, and/or TRIZ-principles, *differs* from “normal” induction and deduction. Both the problem and the paradigm have an openness to the world represented with the circles with dashed lines.

- The proposition is that a good paradigm gives room for creating an *innovative tension* between paradigm and problem, which becomes productive in the analysis of the problem and helps to come up with solutions, functioning as a *transfer* area. As in the Frame Innovation Model [13], and the TRIZ-tool Feature Transfer [18] the good aspects (features) of the paradigm (alternative system) challenge the problem and enable to transfer solutions to the original situation.



Figuur 1 The paradigming perspective

This paradigmatic approach, inspired by the Thomas Kuhn [19] and Giorgio Agamben [1,2], is not meant to substitute the “normal” inductive and deductive use of TRIZ-tools. Rather it could enrich the way of perceiving inventive TRIZ-principles since a paradigm works in its own – analogic – way.

TRIZ-principles are meant to act as “models of solutions” [17, and therefore:

- *Engineers* are invited to suspend the usual inductive and deductive way of looking at problem solving and can discern what it means that the inventive TRIZ-principle could work as paradigms, as illustrated by our educational examples.
- *Teachers* often use examples for explaining the challenges of their disciplines. They are invited to suspend the usual way of looking at examples and to discern that their examples could work as paradigms, as illustrated by the examples of TRIZ and Frame Innovation.
- *Philosophers*, who think about another persons’ thinking, are invited to discern *how* the concrete examples could deepen the “paradigm” philosophy as presented by Kuhn and Agamben and *why* a paradigm “works”.

Since engineers, teachers and philosophers may read this article, first the different *elements* of this approach are described.

## 1.2. TRIZ-principles, Frames and Contextual Approach

The general line of our argument is that inventive TRIZ-principles are seen to be Frames and Frames could be considered as paradigms, which will be evaluated philosophically and which is illustrated by the educational project. This paragraph discusses (1) TRIZ, (2) Frame Innovation and (3) a comparison of both in the contextual approach.

(1) We are going to use the *TRIZ-principles as paradigms* in philosophy education. TRIZ is the theory of inventive problem solving [3] finding solutions for problems by means of *procedures* using the description of the purpose, the resources, analogical solutions, contradictions and modelling of thinking [14,18]. TRIZ aims at *ideality*, and finds the optimal solutions by using principles, derived from the analysis of solutions to problems, to solve its contradictions [14,18]. TRIZ, furthermore, is a way of thinking [18] which works as a compass. The inventive principles work as markers in a roadmap envisioning solutions. In the books of Karen Gadd and Karl Klotze, the same elements of the founder Genrich Altshuller are used, however Gadd approaches TRIZ as a roadmap [14] and Klotze as a process with above mentioned procedures, [18].

One of the TRIZ tools, *Feature Transfer* [18], can be used in an analogic way. With Feature transfer, a base system is improved by transferring beneficial features from a second, analogous system. This is done by comparing the two systems, and attempting to transfer the positive features of one system to replace or enhance the negative features of another system. Feature Transfer starts with (a) identifying the features of your system, those that work well and those that do not work well; (b) thereafter searching for analogous systems, systems that have a similar main function as your system, (c) thereafter, identifying the features that work well and those that do not work well for those analogous systems. The analogous system that has reversed set of features working well / not working well is normally chosen as the system used for the actual feature transfer. In the final step, (d) one tries to transfer the well working feature from the analogous system to the system [15,18].

(2) *Frame Innovation* is a form of design thinking, which focuses on putting Frames beside social design problems. Kees Dorst develops Frame Innovation [13] in addition to Design Thinking. Lakshman sees Design Thinking as a mindset and a culture of the *how*, *what* and *why* for solving a problem [9]. Design Thinking is seen as an impulse to find creative solutions in many businesses [13]. Design Thinking is also used for the creation of educational projects [21]. Dorst proposes his Frame Innovation in contrast to a form of Design Thinking which focus on “[t]he application of some cool design tricks and techniques states” [13]. However, the transposition of Design Thinking to other domains than engineering problems seems not always as successful as hoped for [13]. Dorst explains that Design Thinking focuses on designer’s ability of generating *solutions*; Frame Innovation focuses on the designer’s ability to create new approaches to *problem* situations: “Framing” [13].

A Frame is an organizational principle or a coherent set of statements that are useful to think with [13]. Dorst puts a strong emphasis on the *archaeology* and the *phenomenology* of the *problem*. The designer’s *dialogue* with the problem and its stakeholders reveals the *paradoxes* and embraces the complexity and prevents quick solutions. The elaboration of Dorst’s Kings Cross case will illustrate how Frame Innovation works.

It should be noted that a Frame in the context of Frame innovation is different to Edward De Bono’s [10] lateral thinking method: “Random Entry” to create new solutions. Whereas with “Random Entry” words are chosen randomly, Frames are chosen more deliberately (See 1.3 below) and also represent more complex analogous situations, rather than individual words as starting points, thus leading from trial and error to a more targeted approach.

(3) Both TRIZ and Frame Innovation enable critical and creative thinking for problem solving. The nature of the problems, however, is different. TRIZ originates from solving complex *engineering* problems, whereas Frame Innovation focuses on complex *social* design problems. TRIZ like Frame Innovation *suspends the judgement* in the *paradoxes* and *contradictions* of the problem. The TRIZ-problems focus on the technical and physical contradictions to find

solutions in dialogue with a description of the purpose, the ideal end state, the resources, analogical solutions, paradoxes and modelling of thinking [14,18]. Most engineering problems result in “real” contradictions due to the *laws of physics and thermodynamics*. One classic example: how do you quickly produce many chocolate bonbons with syrup inside? The syrup should be *hot* in order to be poured easily into the chocolate mold *and* the syrup should be *cold* as hot syrup melts the chocolate. Syrup cannot be cold and hot at the same time! [18] The social design problems do not obey as strict as engineering problems to scientific laws. Frame Innovation proposes solutions in a sound dialogue and with knowledge of the archaeology of the problem.

So, for using TRIZ in social design problems, as in the social design project at school, it is important to discover the *similarities and dissimilarities* – the analogical reasoning; in other words, the ability to perceive and use relational similarity between two situations or [15] – between a design approach of engineering problems and a design approach of social problems. The *philosophical, contextual approach* focuses on disclosing the presuppositions of the both design perspectives by using a paradigmatic case, which will be discussed in the next paragraph.

### *1.3. Frame Innovation Applied: The Kings Cross Case*

In this paragraph, (1) the King Cross case is explained, (2) how a musical festival is used as a Frame and (3) how this differs from a “traditional” inductive/deductive approach to problems.

(1) Dorst did extensive research with his team on the *Kings Cross* entertainment district of Sidney. This case study is the *leading example* for our social design project. Kings Cross has experienced continuous problems, like drunkenness, fights, pickpocketing, minor drug-dealing, sporadic violence. With its bars and its slightly grubby nightlife (it has a history as a red-light district), this area attracts about 30,000 young people on a Friday and Saturday night [13]. What is a similar situation *without* these problems?

(2) A music festival is a Frame, a good paradigm, to question Kings Cross. Experts, with “a successful music festival” in the back of their mind, visited Kings Cross and were able to point out dozens of “bottlenecks” without difficulty. There were far too few public toilets, no public transport between one and five, no relax spaces for people who had used too much alcohol or drugs, and the youngsters had a lot of possibilities to get bored, if the clubs were too crowded. The police actions and presence in Kings Cross were the embodiment of *care* for the teenagers. The whole problem of Kings Cross was extensively analyzed, resulting for instance in deepening the theme of *care* for youngsters. Before the intervention of Dorst and his team, “taking care of the teenagers” meant “protecting them”, and “protecting them” meant “police control”. Dorst asks: Does “care for youngsters at Kings Cross” mean “police control”? [13]. After the intervention – beside many other improvements – the presence of police officers was reduced in favor of youth guides in bright T-shirts of more or less the same age as the youngsters as common at music festivals [13].

(3) This and other Frame Innovation case studies [13] illustrate, that there is no easy prefabricated solution. An extensive investigation in dialogue with all stakeholders is needed. Whereas in the engineering world a next step has been the creation of paradox matrices like the contradiction matrix of Genrich Altshuller [3], the inventor of TRIZ, this is not so easy for social design problems. Dorst’s argument demonstrates that justly social design problems do not obey to inductive and deductive “*logic*” of strict scientific laws, but obey to the “*dia-logic*” of seeing, thinking and doing differently [13].

## 2. The Social Design Project

In this paragraph we discuss the educational background and the provisional result of the our project.

### 2.1. Educational background

In the 10<sup>th</sup> grade 2016-2017, this class of 13 students did a philosophy project on the Anthropocene as described by Johan Rockström [22] using the Big History Project, initiated by David Christian, including the rubrics [4], which are used for grading. This school year 2017-2018 our school got involved as a Brainport [6] school with an innovative project concerning TRIZ and dialogical teaching. For the social design project we established the following learning goals:

- The student creates / ideates a social design problem containing paradoxes in for example: aging, work-private life issues, safety, internet of things, liveable environment in the future, the use of robotics in the society or education [11, 23]. [a] The student connects the problem to a Frame or Frames and to the TRIZ-principles. [b] The student applies anthropology, epistemology, philosophy of science, political and/or social philosophy and ethics in the Frame, as taught earlier.
- Future skills: The student uses reading, investigation skills, writing skills as proposed by the Big History *rubrics* to “attack” a complex real life problem using critical and creative thinking and problem solving technics; meanwhile the student gets an idea of what is needed for “future” profession, like T- or M-shaped-professions [8].
- The student develops a philosophy about how a paradigm, a Frame and a TRIZ-principle “works” using for example the philosophical perspectives of Dorst [13] or Agamben [2].

### 2.2. Provisional results of the social design project

The project took place in April, May and June 2018. As a first step, students had to find an interesting social design problem (like Kings Cross). They had to identify the underlying paradox(es) (for example: Is “care” as applied at a music festival comparable to “control” as applied at Kings Cross?) and to find an interesting Frame (for example: the music festival for King Cross). The students came up with a number of interesting social design problems.

- Should an animal ambulance become a priority vehicle? [Frame: auto race]
- How could be differentiated for different students abilities in education? [Frame: children in a family]
- Why do we limit the amount of students in health care, while having a shortage of doctors in the Netherlands? [Frame: selection of athletes in sports teams ]
- Why do teenagers drink alcohol while they know that it damages their brain and it is prohibited for under 18? [Frame: little changes of behaviour knowing about the climate changes because of greenhouse effect]
- How to stop overweight? [Frame: the (government) approach for quitting with smoking]

The case material, their philosophy courses, the rubrics in a dialogue between student and teacher and the application of the TRIZ-procedures should lead the students to write an essay. Some provisional observations:

- What struck from a teacher's perspective was how easily students came up with interesting *Frames* and paradoxes and that it was *easy* for the students to think with them.
- In dialogue with the students, the provisional conclusion, that *one* Frame may not be enough for complex situations/systems. Ambulances, for example, need to race to arrive quickly at the hospital, but do they need to win? In the background, the philosophical anthropological question of the differences between human beings and animals is at stake.
- Whereas engineers are capable of using the TRIZ-principles in an abstract sense, for our students it was useful to see the TRIZ-principles *illustrated* [cf. 14]. Somehow the example which illustrated the principle was more important than the abstract principle itself. The illustration of the principle seemed to function like a Frame.
- In the dialogue with students, it appeared that the more *universal TRIZ-principles* [18], like segmentation, taking out, the local quality, merging, universality, prior counteraction, dynamics, another dimension were considered as principles representing clear examples as illustrated by Gadd [14]. The *segmentation-* of the *universality-*principle were like *synonyms* for steps taken in an *analysis* of a problem. Intuitively, these perspectives were considered to be principles of the *empirical cycle* as studied in philosophy. The empirical cycle proceeds from hypothesis to hypothesis by means of observations, data analysis and discussion. The inventive principles work as catalysts to deepen the problems and predict possible solutions.

At the moment of writing this paper, the students have well understood the Frame Innovation approach of Dorst by means of the Kings Cross example, they formulated a social problem, paradoxes involved and possible Frames to investigate the social design problems.

An application of the inventive TRIZ-principles to the Kings Cross case is presented, which was in line with the student's expectations of how the inventive TRIZ-principles "work" [cf.13].

- 1 Segmentation: The music festival can analysed from the perspective of many stakeholders: youngsters, clubs, police, public transport;
- 2 Taking out: the fact that there are basically youngsters: how could you make the area more attractive for people with more different ranges of age?;
- 3 Local quality: the district of the Kings Cross, there is the possibility of permanent 24/24 public transport, which could be used by the teenagers of Kings Cross;
- 5 Merging: care and protection given by the police officers and care given by the guides of the festival can be merged into wellbeing for all the stakeholders;
- 6 Universality: moments of boredom will be eliminated when there is hundred percent time of attractive entertainment;



- 10 Prior counteraction: drunken people, who do not find the way to the station, could be guided to the station by light indicators projected on the pavement. Lights could also prevent urinating at dark places;
- 15 Dynamics: see the object / area in a broader perspective and making it interesting to go to for people of all ages, creating also a buffer of other ages than the youngsters
- 17 Another dimension: another dimension of care giving: care instead of control.

Resource Analysis and the Feature Transfer [18] help to illuminate the paradoxes and to explicate the dialogue between Frame and problem, as shown in application of the inventive TRIZ-principles. At present only a first impression of the draft versions was available. The dialogues with the students are very promising, also because many concepts studied in earlier philosophy courses receive a place in their design project.

### 3. Philosophical evaluation on the social design project

In this paragraph the philosophical perspectives of Thomas Kuhn (1922-1996) and Giorgio Agamben (1942) paradigms are discussed, and it is illustrated what this could mean with respect to the TRIZ-principles, the Kings Cross case and the educational situation.

#### 3.1. *The a Kuhnian scope of a paradigmatic approach*

The concept *paradigm* has become well known because of the book: *The Structure of Scientific Revolutions* of philosopher and scientist Thomas Kuhn. A paradigm is “what the members of a scientific community share *and*, conversely, a scientific community consists of men who share a paradigm” [19]. The paradigms refer to “the constellation of group commitments”, “shared examples”, “to shared knowledge and intuition” [19]. The paradigm which Kuhn has in mind is not a scientific law, but the *use* of a law by scientific community, learning to understand the phenomena of nature. Kuhn has also a *student of science in educational situation* in mind and his relation to the phenomena of nature. Shared examples of the relation between nature and the way a scientific community perceives and works with nature, should be what student should learn. Kuhn observes with hindsight in the second edition of his book: “The paradigm as shared example is the central element of what I now take to be the most novel and least understood aspect of this book.” [19]

Agamben observes the distinction between *exemplar* from *exemplum* in Latin, which could help to understand better what “paradigm as shared example” means. The *exemplar* is observed by the *senses* “and refers to that which one must imitate”. The *exemplum*, on the other hand, demands a more complex, moral and *intellectual evaluation*. Agamben states that the “paradigm is both of these things: not only an exemplar and model, which imposes the constitution of a normal science, but also and above all an exemplum, which allows statements and discursive practices to be gathered into a new intelligible ensemble and in a new problematic context.” [2].

It seems that “paradigm as shared example” for Kuhn has a similar implication as the paradigm for Agamben. The student should not only learn theory and apply rules (“he may gain only *added facility* by solving more” [19]), which is only the intellectual evaluation. The student also *sees* that the laws are embedded in real nature (“But at the start and for some time after, doing problems is learning consequential things about nature” [19]).

Analogically, a concrete music festival as reality is an example for learning about entertainment events in entertainment studies. And if you perceive at a concrete and abstract level what an entertainment event is, you can apply it also to other entertainment situations, like Kings Cross. *And, moreover, if you understand inventive TRIZ-principles, Resource Analysis, Feature Transfer from within, you can apply them also analogically to non-engineering problems, because you perceive the phenomenon as totality of the concrete reality embodying the implicit laws involved in the phenomenon.*

In the sense that a scientific law has *real relation to reality* (as Kuhn explained above), analogically inventive TRIZ-principles have a relation to problems one tries to solve with them. However, they will be only recognized by members of the scientific community which embrace these principles.

The following text of Kuhn could be instructive to understand how inventive TRIZ-principles could “work” in an educational context. Students of science

regularly report that they have read through a chapter of their text, understood it perfectly, but nonetheless had difficulty solving a number of the problems at the chapter’s end. (...) The student discovers, with or without the assistance of his instructor, a way to see his problem as like a problem he has already encountered [which could be a Frame or a TRIZ-principle applied in an earlier problem]. Having seen the resemblance, grasped the analogy between two or more distinct problems, he can interrelate symbols [like inventive TRIZ-principle] and attach them to nature in the ways that have proved effective before. The law-sketch, say  $F = ma$ , has functioned as a tool, [again like TRIZ-principles] informing the student what similarities to look for, signaling the gestalt in which the situation is to be seen. The resultant ability to see a variety of situations [like situations where TRIZ-principle are applied] as like each other, as subjects for  $F = ma$  or some other symbolic generalization, is, I think, the main thing a student acquires by doing exemplary problems, whether with a pencil and paper or in a well-designed laboratory. After he has completed a certain number, which may vary widely from one individual to the next, he views the situations that confront him as a scientist in the same gestalt as other members of his specialists’ group. For him they are no longer the same situations he had encountered when his training began. He has meanwhile assimilated a time-tested and group-licensed way of seeing. [19]

Likewise a TRIZ-community has its own group-licensed way of seeing, and students can learn community related complex ways of thinking and solving problems. And, again analogically, one could state that you can learn from the gestalts in nature, like in biomimicry [5].

In conclusion, a good example, a good paradigm should be rich in that it offers many roads, at least some of the roads are relevant to the original, and it also tells a story which makes it understandable. Furthermore it should have some distance, some room for interpretation, like the space we indicated around the paradigm (see figure 1). This space is where hitherto unrelated elements could be fruitful in innovative processes, of design and learning.

### *3.2. The an Agambenian scope of a paradigmatic approach*

As presented in the title, the present project is called paradigmging. Kuhn described the phenomenon of a paradigm in scientific community and how students should be formed more in the paradigmatic view and practice of community rather than only in the abstract knowledge and laws of community’s discipline. Agamben leads a step further in perceiving the paradigm as a method. Although he does not want to call his approach methodical or epistemological [1], it gives the opportunity to reflect what a *epistemology of a paradigm* could be.

Agamben mentions a few classical sources to think about a paradigm. Aristotle distinguishes the procedural approach of paradigms from induction and deduction. *Induction* functions from the particular to the universal: I see one white swan, two, three, a thousand, a million, so all swans are white. *Deduction* functions from the universal to particular. All human beings are mortal. Socrates is human being. Socrates is mortal. Universal scientific laws are found by means of many particular experiments (induction). And particular predictions are done based on universal laws (deduction). So science basically “works” by means of induction and deduction. *Nota bene*, this is how TRIZ normally is applied. A particular problem as a starting point, is first generalized (induction), then a general solution is identified, and finally the general solution is applied for the specific problem (deduction).

However, as Aristotle states that a paradigm functions “as a part with respect to the part, if both are under the same, but one is better known than the other” [2]. According to Agamben, the paradigm “calls into question the dichotomous opposition between the particular and the universal inseparable form procedures of knowing, and presents instead a singularity irreducible to any of the dichotomy’s two terms” [2]. And the domain of the paradigmatic discourse is not the logic, but *analogy*.

With Melandri, Agamben states that the analogy, the paradigm *transforms* the particular and universal: The “analogy intervenes in the dichotomies of logic (particular/universal; form/content; lawfulness/exemplarity; and so on) not to take them up into a higher synthesis but to transform them into a force field traversed by polar tensions, where (as in an electro-magnetic field) their substantial identities evaporate.” [2]. In dialogue with Kant, Agamben confirms that the paradigm “entails a movement that goes from singularity to singularity and, without ever leaving singularity, transforms every singular case into an exemplar of *general rule*, that can never be stated a priori.” [2] “Plato shows the etymology of paradigm: “placing alongside”, “conjoining together”, “showing”, “exposing” and makes Agamben conclude: “The paradigmatic relation does not merely occur between sensible objects or between these objects and a general rule; it occurs instead between a *singularity* (which thus becomes a *paradigm*) and its *exposition* (its *intelligibility*).” [19]

So the paradigm exposes in an analogical, tensional area, the intelligibility in a relation from singularity to singularity, when a paradigmatic singularity is exposed alongside another singularity. In the context of the present paper this means: the music festival shows its intelligibility by being exposed alongside to Kings Cross. Or the inventive TRIZ-principles show their intelligibility by being exposed alongside to King Cross. (1) TRIZ-principles could work as *universal* principles, in *that* case the Kings Cross is the *particular* case and the TRIZ-principles will be treated in *deductive logic* way in relation to the particular social problem (cf. figure 1). (2) And if, and this is maybe *new for TRIZ-engineers*, the *TRIZ-principles are approached as singularities* (by means of the examples used to illustrate of these TRIZ-principles) a discursive analogical process from singularity to singularity is initiated. The analogy does not show only the *logos* (logic) but also the *pathos* of the principle, the archetype of the phenomenon, a first-timeness (*primavoltità*) of the phenomenon. This is what Goethe calls the originary phenomenon (*Urphänomen*) [2]. “As a paradigm, the *Urphänomen* is thus the place where analogy lives in perfect equilibrium beyond the opposition between generality and particularity.” [2] In other words, the whole problem (the gestalt, as Kuhn would say) from which the TRIZ-principle are induced, resonates in dialogue with the problem under investigation, showing the *pathos*, with which the problem was solved. And indeed, this is not a scientific law, but a phenomenological approach of a scientific community – look around at the TRIZ-festival! According to Agamben this paradigmatic vision of reality is grounded in reality:

If one asks whether the paradigmatic character lies in things themselves or in the mind of the inquirer, my response must be that the question itself makes no sense. The intelligibility in question in the paradigm has an ontological character. It refers not to the cognitive relation between subject and object but to being. There is, then, a paradigmatic ontology. And I know of no better definition of it than the one contained in a poem by Wallace Stevens titled “Description Without Place”: *It is possible that to seem – it is to be, As the sun is something seeming and it is. The sun is an example. What it seems. It is and in such seeming all things are.* [2]

Agamben summarizes with the following six points a complex *definition* of a paradigm [2]. In the margins, are illustrated the six aspects of his definition of the paradigm with TRIZ-principles and with Kings Cross as Frame Innovation example.

1. *A paradigm is a form of knowledge that is neither inductive nor deductive but analogical. It moves from singularity to singularity.* – In a good example, the frame or principle, the paradigm used, initiates a dialogue between the singular problematic with unclear intelligibility and a paradigm with clear intelligibility.
2. *By neutralizing the dichotomy between the general and the particular, it replaces a dichotomous logic with a bipolar analogical model.* – Although Kings Cross (singularity) and the music festival (singularity) belong to the genus of “entertainment for teenagers” (general) this dichotomy between general and particular is replaced by bipolar analogical model where the good example marks the problematic situation.
3. *The paradigmatic case, by suspending and, at the same time, exposing its belonging to the group, makes it impossible to separate its exemplarity from its singularity.* – The paradigm of music festival can be used as paradigm as long as it is not forced to belong to a general group (genus). Teachers often see the genus, student do not; they see the *pathos* of the problem! Understanding how a paradigm works could illuminate students to see the general picture.
4. *The paradigmatic group is never presupposed by the paradigms; rather, it is immanent in them.* – That the paradigmatic group is never presupposed by the paradigms, means, that a general group cannot be induced or deduced from a paradigm. A singularity is a paradigm for other singularities suspending the law it could represent (the building of a pyramid could be a paradigm for the twelfth TRIZ-principle of equipotentiality [14], but it could also be seen as an example of asymmetry [14] ). The music festival has immanent qualities that makes it a good paradigm for Kings Cross, but it is not presupposed in the music festival as such.
5. *In the paradigm, there is no origin or archē; every phenomenon is the origin, every image archaic.* – Every phenomenon could be used as paradigm, since there is no origin in the paradigm. Every phenomenon shows beside itself and has the potentiality to show beside itself, thus acting beside itself. It is the student’s and teacher’s challenge to find the good phenomena, which could work as paradigm.
6. *The historicity of the paradigm lies neither in diachrony nor in synchrony but in a crossing of the two.* – A paradigm is overarching diachronic and synchronic time. The panopticon of Bentham in the reading of Foucault has this quality being a paradigm for supervising power (Agamben, 2009 16). When you have an idea of what the panopticon is – a curricular prison, you experience immediately that it is a good paradigm for supervising power.

The paradigmatic approach is characteristic for Agamben's way of philosophizing. What this could mean for *educational theory* is well developed by Meskin and Shapiro [20]. However, it would be worth investigating what this more theoretical approach could mean for practical pedagogical, the didactical situations, like teaching chemistry or the Kings Cross case presented in this paper.

#### 4. Conclusion: In-Segnare: Marking Education with Paradigms

This is also an answer to the initial question: *How* and *why* do TRIZ-principles "work" in education? TRIZ-principles "work" as good paradigms, show the intelligibility of an originary phenomenon, especially if they are illustrated with examples. In Cavallucci [7] you find a partial view of a "problem graph" representing the contradictory arguments concerning a bottle blow process a: *network of boxes connected with arrows*. This representation of the problem is a good example, if the problem graph represents the tensional dialogue of experts, and if this graph as a singularity could be used as an example, alongside another problem and in some way encourage the dialogue about your problem with the dialogue of the bottle blow process.

In educational language, teaching students is perceived as transfer of knowledge and skills from the teacher and the teaching material to the students [16,24]. Of course, teaching English, chemistry, economics means also teaching the *deductive and inductive principles* of these disciplines and the teacher's relation to his/her subject. And if students learn by means of examples, the examples should exemplify the principles of the disciplines and good relation to the discipline: a good *pathos*. Teaching his/her relation to the subject is a paradigm on its own, like good TRIZ-engineers and Frame Innovation designers: it is a *forma vitae* [2]. However, more complex and open tools seem to be needed to solve complex problems like Kings Cross. *Learning by (finding) paradigms – paradigmizing* – is an alternative, which have been proposed in this article as approach for "solving" more complex and open problems.

Frame Innovation and the TRIZ-principles could be good paradigms to help students discover the simplicity of the discipline in the complexity of the problem. *How?* By learning to put paradigms in the margins of the problematic situation or assignment to illuminate the problems; *Frame Innovation and Feature Transfer for more complex problems, and the TRIZ-principles for the more specific and precise aspects of these problems*. And *why* does it work? As above mentioned, because Frames and TRIZ-principles "work" as good paradigms, representative for the complexity of problems and assignments, and because paradigms (like good road maps) interact with the assignment itself.

Finding good paradigms is an *art*, in which you need to find the right mindset, as the example of Feature Transfer seems to indicate there are some rules, some structure that may be applied. The Frames and the TRIZ-principles are like pieces of good art, which presuppose understanding the problem by seeing, thinking and doing differently (Dorst), hence the importance of Dorst's, Kuhn's and Agamben's analyses. Paradigms, Frames and TRIZ-principles operate as anchor points or *signatures* to mark – Agamben uses the Italian *segnetura* and *segnare* (2009), related to *insegnare*, to teach – the problem.

The auto race has marked the animal ambulance challenge; the family approach: education; the stop-smoking campaign: the overweight; environmental problem approach: the alcohol approach of teenagers. The uniqueness of every paradigm is a fresh experience [20] putting the student in dialogue with the complexity of reality and fostering his or her inherent creativity.

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**Communicating Author:** [r.heesen@varendonck.nl](mailto:r.heesen@varendonck.nl) / [ruudheesen@yahoo.com](mailto:ruudheesen@yahoo.com) / [c.dobrusskin@philips.com](mailto:c.dobrusskin@philips.com)

## TRIZfest 2018

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# A FRAMEWORK FOR USING TRIZ TO SOLVE ADDITIVE MANUFACTURING CHALLENGES

Vinodh Mewani<sup>a</sup>, G. Nagashiresha<sup>b</sup>

<sup>a</sup>*Global Patents Operation, GE Global Operations, Bangalore-560066, India*

<sup>b</sup>*Advanced Technologies, GE Aviation, Bangalore-560066, India*

### Abstract

Additive manufacturing (AM) is a technique that is typically employed to build complex shaped components by adding layer-upon-layer of material. Application of AM is limitless from making end-use products for aircraft to dental restorations to medical implants to automobiles to jewelry. But as any niche technology, use of additive manufacturing does come with multiple challenges and limitations. Though there are several advantages of using AM as an alternate manufacturing method for specialized, high end products such as in aerospace industry, there are still so many challenges across the value chain of additive manufacturing for its commercialization, mass production and repeatability. Some of the typical challenges faced by AM community are Design optimization, topology optimization, surface finish of the product, increasing the production speed, overall quality and repeatability of part production, expanding the number of materials available for additive manufacturing with tailored properties for the process, to name a few. With newer applications arising, newer challenges arise.

Additive manufacturing challenges the existing design experience and methodologies by offering a large design solution space. This design freedom creates a vast solution space for technical design problems. Most approaches show a trial-and-error methodology by the designer relying on existing design experience. This paper describes a framework of TRIZ tools for additive manufacturing through which the user can consolidate and optimize a product design for AM. The authors have tried to focus more on design optimization and part consolidation challenges of AM and how TRIZ can provide innovative and customized design solutions.

Keywords: TRIZ, additive manufacturing, Design for additive, DFAM, dishwasher, fluid filtering

## 1. Introduction

Additive manufacturing (AM) enables fabrication of complex structures, ranging from the overall geometry of a part to the topology of its internal architecture to the spatial distribution of its material composition. Along with this freedom of fabrication comes the challenge of designing for additive manufacturing. The challenges include representing and optimizing intricate geometries and functionally graded structures, incorporating Design for AM knowledge into the design process, and making Design for AM tools and knowledge more accessible to a broad range of expert and novice designers. Researchers are actively investigating many of these topics, but significant advances are needed if AM is to revolutionize and democratize product design as we



know it [1]. With the capabilities of additive manufacturing, it is necessary to have practical design frameworks or methodologies that can enable designers to generate effective product designs for additive manufacturing [2, 3]. In this regard, the concept of Design for Additive Manufacturing (DfAM) has risen to provide a set of guidelines and tools that facilitate the consideration and evaluation of additive manufacturing during a product design process [2]. However, DfAM approaches in the literature have several issues that must be tackled to derive appropriate design solutions for additive manufacturing. First, they tend to rely on the direct application of existing design methods for conventional manufacturing without their appropriate translations for additive manufacturing; therefore, the process of additive manufacturing is often disregarded in the early design phase [3]. Also, only few methods among the existing DfAM approaches systematically analyze design problems and generate creative solutions [4]. Furthermore, there is a lack of DfAM methods suitable for additive manufacturing novices.

To tackle the above issues in DfAM, this study provides various TRIZ tools and methodologies that integrates the design theory and the theory of inventive problem solving (TRIZ). An axiomatic design approach systematically defines design problems by mapping associated functional requirements, design parameters, and process variables [5]. On the other hand, the inverse problem-solving approach in TRIZ derives design parameters that satisfy functional requirements [6]. Today AM designers are relying on existing design practices to design a part for AM. DfAM approach are taking buildability, material availability, mechanical aspects (stress, load etc.), cost optimization, support structure optimization etc. as design considerations rather towards function or performance and physical parameter based design approach. Authors have conducted extensive literature survey and did not find an approach of integrating some of the aspects of TRIZ to DfAM to tackle some of the challenges mentioned above and provide a structured approach. Hence, they attempted to apply some of the tools and methods of TRIZ to generate innovative and cost-effective design solutions using a case study. For example, authors have tried to use MPV based analysis [7] for formulating a clear design objective and rank those MPVs based on S-Curve analysis [8] and product stage in the market.

Fig 1 below shows the typical design process followed in additive manufacturing industry.

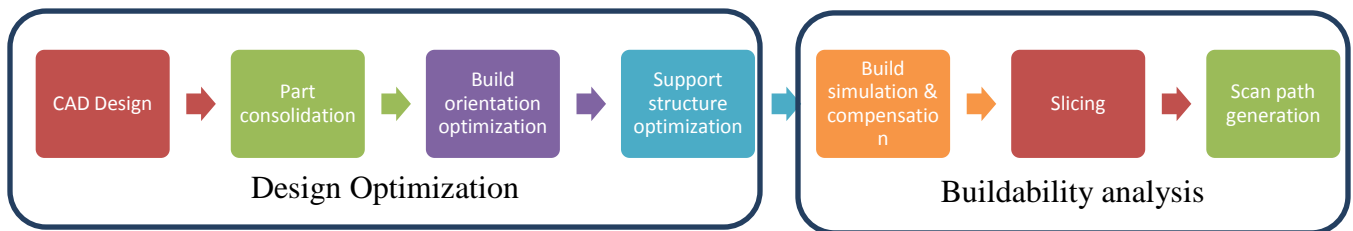


Figure 1: Typical AM design process

In the current study, authors have tried to bring the best practices of TRIZ and adapt it for design optimization in AM. Design optimization is typically done based on the mechanical load requirements and constraints. Design is optimized to meet different mechanical property requirements of a component, like,

stress, strength, weight and stiffness. Most often it is an iterative process where the project requirements keep getting refined until the best design solution is found. In many cases, design objective will not be clearly defined where the customer requirements are not broken down to physical parameters and functional requirements. Authors have tried to use main parameter value (MPV) based analysis to break-down the customer requirements to physical parameters and rank those MPVs by looking at the stage of the product in S-Curve analysis. This method can provide a clear direction and focus on the “must-to-have” parameters in the design. Another challenge in AM design optimization is support structure optimization. Support structures are desirable in AM parts that have complex design features or overhangs to avoid thermal distortion during build process. On the other hand, they are not desirable as they increase the build time, cost of the process and amount of powder being used. Today designers use commercially available software to optimize the support structures that automatically throws various options to select the type of support and orient the part. Authors have proposed the use of physical contradictions and 40 inventive principles to optimize or eliminate the need for support structures. Another major step in additive manufacturing design process and one of the major drivers for the adoption of additive manufacturing in today’s world is its ability to consolidate the number of parts and provide a low weight and compact design. There is a beautiful method available in TRIZ tool kit called functional analysis and trimming which provides the designer a structured approach to consolidate the part and at the same time eliminate some of the harmful and insufficient functions. Below table gives you the details of the design challenges and corresponding TRIZ methodology for better innovative product designs. Authors have tried to explain this approach with the help of case study

Table 1

Design Challenges Mapping with TRIZ Tool

Design Steps	Typical Process	TRIZ methodology/tool
Objective of Design	Study of current design and analyze the requirements to generate new design with constraints	MPV analysis, Ideal Final Result (IFR)
Support structure optimization	DoE, optimization algorithms, statistical analysis, topology optimization.	Resource Analysis, Design the component solving the restrictions or constraints using 40 inventive principles, ARIZ, Su-field model
Part consolidation and cost optimization	Analysis of current design and follow the requirements to generate the design with constraints, sometimes using a commercially available software	Functional analysis of components, Trimming and redesign

## **2. Case Study: Design a dishwasher having an improved filtering system for the removal of particles from wash fluid and limit clogging of filtering system.**

**Motivation:** During wash and rinse cycles, dishwashers typically circulate a fluid through a wash chamber over articles such as pots, pans, silverware, and other cooking utensils. The fluid can be e.g., various combinations of water and detergent during the wash cycle or water (which may include additives) during the rinse cycle. Typically, the fluid is recirculated during a given cycle using a pump. Fluid is collected at or near the bottom of the wash chamber and pumped back into the chamber through e.g., nozzles in the spray arms and other openings that direct the fluid against the articles to be cleaned or rinsed. Depending upon the level of soil upon the articles, fluids used during wash and rinse cycles will become contaminated with soils in the form of debris or particles that are carried with the fluid. To protect the pump and recirculate and avoid clogging of the spray nozzles, it is beneficial to filter the fluid so that relatively clean fluid is applied to the articles in the wash chamber and materials are removed or reduced from the fluid. Current mechanical filters have a limitation w.r.t the selectivity of the size of the filter and pore size to address the issue of filtering both small and large food particles and to avoid multiple wash, rinse cycles. Hence, the objective is to design a dishwasher appliance with an improved detergent/washing liquid filtering system.

### *2.1. TRIZ Approach: Main parameter value analysis for Design objective*

Main parameter value (MPV) analysis is a methodology to find MSPV (Main Strategic Parameter of Value) attributing customers' behavior in the market and change it to the MFPV (Main Functional Parameter of Value). It is also trying to search latent MPV, too. It differs from conventional design because customer needs and functional needs are in the same hierarchy. MPV starts from generic terms but starts to guide the parameter to the main functional parameter of the value. This is done by breaking down high level MPVs into physical parameter values. One MPV can have multiple physical parameter values. Based on MPV criticality and importance, ranking is given and accordingly those parameters become the must-to-have parameters to consider during the design of product. For MPV ranking, S-Curve analysis can also be considered to identify which stage a product is lying in and rank them. For example, if the product is in its first stage of S-Curve then functional and performance requirements takes a higher priority and ranking than cost and aesthetics. An example was shown using a design of dishwasher appliance in flow chart as shown in Fig 2 and Table 2 below to identify the parameters that matters most.

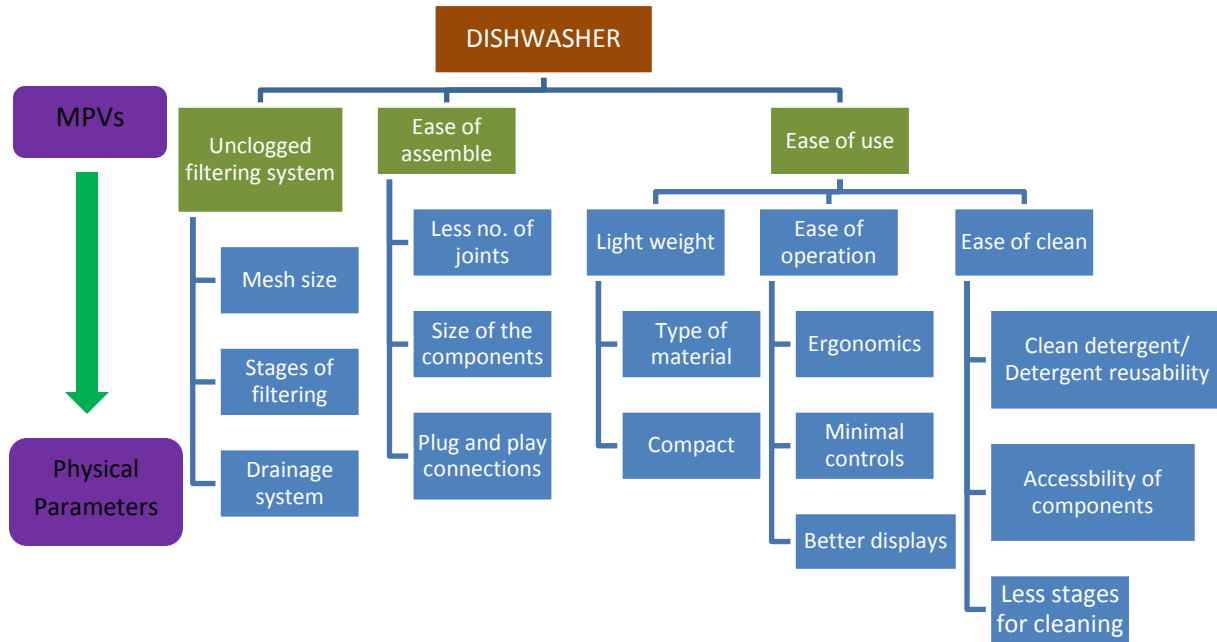


Figure 2: Flow chart showing the MPV analysis

Table 2

### MPV Category and Ranking

MPV	Parameter Value	Rank	Category
Unclogged filtering system	Mesh size, Stages of filtering, Drainage system	3 (High/Important)	Must-be parameters. That needs to be improved immediately
Ease of assembly	Less number of joints, Size of the dishwasher, Plug & play connections	2 (Medium)	Expected to be parameters. Present in the existing designs
Ease of use	Light weight- Type of material, Compactness	2 (Medium)	Expected to be parameters. Present in the existing designs
	Ease of operation-Less number of controls- Ergonomics, Ergonomics, Better display system	2 (Medium)	Expected to be parameters. Present in the existing designs
	Easy to clean- Clean and reusable detergent, Accessibility of parts, Less stages of cleaning cycle	3 (High/Important)	Must-be parameters. That needs to be improved immediately

Based on the above MPV analysis, we understood the physical parameters of each MPV that needs to be addressed for a customer requirement (MPV) and accordingly the design objectives

are met without compromising on constraints and achieving more than the customer wants or expects. Fig 3 below shows an example of dishwasher with washing fluid filtering system.

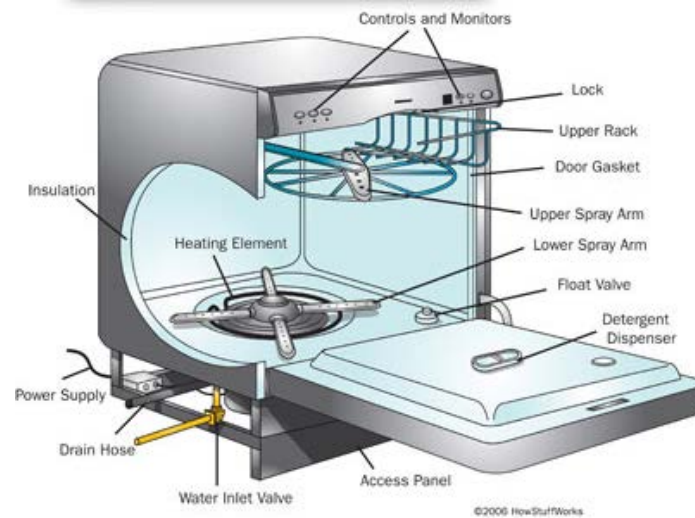


Figure 3: Dishwasher with washing fluid

## 2.2. Support structure optimization

Support structure optimization is one of the key and important step of AM design process. The best and ideal design would be a part with less or no supports. Practically it may not always be possible to print a part without supports, especially if the support has overhangs or complex features. In this case of dishwasher, one of the parts the designer wants to optimize is the spray arm used to spray or distribute water and detergent on the soiled vessels. Fig. 3 below shows view of a t-shape spray arm with bearings and washers inside the spray arm which is going to be additively manufactured. As per AM design rules the design has overhangs and needs to be supported to be built without any distortion. Adding support structures will add time and the cost the process. There exists a physical contradiction that needs to be resolved. The contradiction is framed and shown in Table 3.

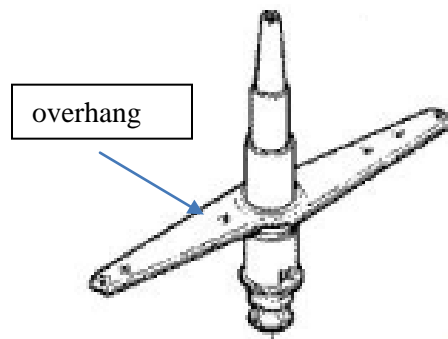


Figure 4: Dishwasher spray arm

Table 3

Physical Contradictions

Physical contradiction	Ways to resolve	Direction	Principles	Solution
Support structure should be present to reduce distortion, but not to be present to reduce process time	Satisfying demands	--	36. Phase transition 37. Thermal expansion 28. Mechanical substitution 35. Parameter changes 38. Strong oxidants 39. Inert atmosphere	28. Instead of solid physical support, whether the inert atmosphere in the build chamber can be pressurized to provide the necessary support, like an air curtain
Support structure should be present to reduce distortion, but not to be present to reduce process time Satisfying demands --	Separating contradicting demands	Separation in time	15. Dynamics 34. Discarding and recovering 10. Preliminary action 9. Preliminary anti-action 11. In-advance cushioning	34. Using reusable support structures made of phase transition material that can used for multiple builds. 9. Re-orient or redesign the part to avoid supports itself. Instead of 90 deg. angle between the arm and base, have an obtuse angle.

Hence, using TRIZ to optimize support structure provides multiple avenues to reduce or eliminate the need of support structures without compromise in the product design.

**2.3. Part consolidation:** To stay competitive in modern manufacturing environment, products should be designed and manufactured within the following two contradicting objectives: decreasing time and cost; increasing quality and flexibility. Reduction of number of parts of a component has been receiving more and more attention in the past decade as one of the effective ways to reduce process time and cost. One feasible way to realize part count reduction is part consolidation which is defined as a process of composites fabrication in which multiple discrete

parts are designed and fabricated together into a single part, thus reducing the number of fabricated parts and the need to join those parts together. Firstly, there is no need for dedicated tooling, for example, fixture, and fasteners and potential assembly difficulties like joining method is avoided. Furthermore, it is often possible to design the consolidated parts to perform better than the assemblies. AM enables part consolidation method and promises a more effective way to achieve part count reduction and the ease of assembly compared with traditional Design for Manufacture and Assembly (DFMA) method. However, how to achieve AM enabled part consolidation is not well developed. In this paper, authors have tried to use it by doing TRIZ based functional analysis of the engineering system, identifying the harmful and functions, build a trimmed function model.

Let's now consider the current system under consideration, namely, filtering mechanism for wash fluid of dishwashers. Depending upon the level of soil upon the articles, fluids used during wash and rinse cycles will become contaminated with soils in the form of debris or particles that are carried with the fluid. To protect the pump and recirculate the fluid through the wash chamber, it is beneficial to filter the fluid so that relatively clean fluid is applied to the articles in the wash chamber and materials are removed or reduced from the fluid. In conventional approach, a filter is employed to separate out the food particles to enable the fluids to recirculate. The disadvantages with the current system are inefficient filtering as the pore size restricts the amount of food particles that can be filtered out. This also leads to frequent clogging of pipes that necessitates the removal of pipes to unclog. As a result, fresh water and wash fluid must be pumped in for circulation. This leads to loss of time as well as increased cost for the end-user.

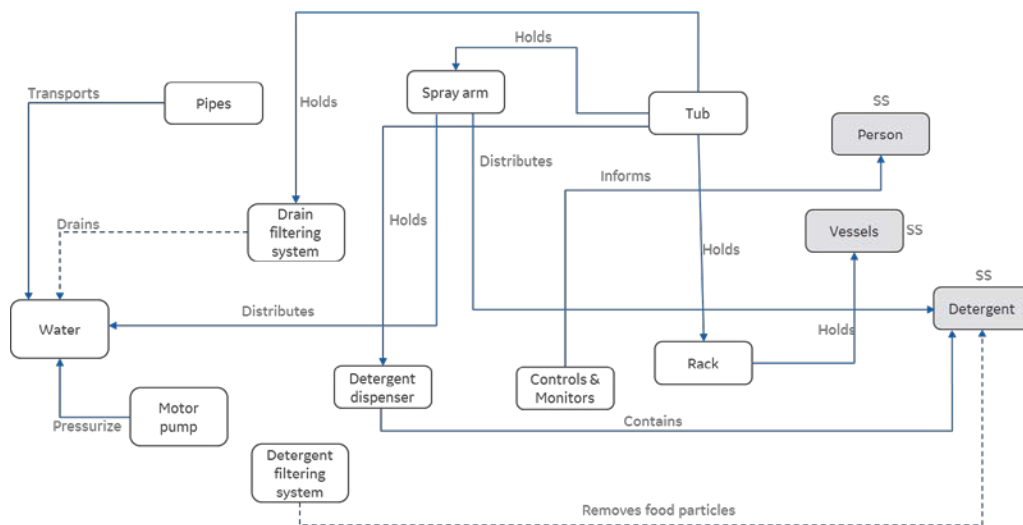


Figure 5: Components of dishwasher

A simple function model of the dishwasher function is shown in Fig. 5 above. The super-system components are colored grey and indicated by “SS” next to the box. As discussed, detergent filtering system removes food particles from detergent insufficiently.

By performing TRIZ based contradiction analysis, the authors concluded that to attain efficient filtering, it would be beneficial to have a filtering system with different pore sizes at different portions, say, a coarse filter at the top followed by a fine filter at the bottom portion. Or a filtering system that is graded in pore size along the radial dimension of the filtering system. Further, the filtering efficiency can also be improved by having a filtering medium that has a complex shape (rippled or convoluted) instead of being planar. When filter medium is rippled or convoluted, the filtering capacity of filter medium increases significantly relative to when outer surfaces of filter medium is flat or planar, e.g., due to the increased surface area of rippled surfaces relative to flat surfaces.

Such complex surfaces as well as complex filtering system is difficult to manufacture using conventional techniques like injection molding. These, on the other hand, can easily be manufactured by additive manufacturing. Thus, integrating TRIZ based methodology with design optimization enables creative and novel ideas that can satisfy the conflicting requirements as well as MPVs.

Also, the 3 major mechanical components in the function analysis – drain filtering system, detergent dispenser and rack are all connected to the dishwasher tub. But, typical dishwashers have the detergent filtering system as a stand-alone though it is very much correlated to detergent dispenser. Trimming analysis showed that detergent filtering system could also, potentially be integrated with the dishwasher tub. This would result in part consolidation leading to compact design and cost optimization could be achieved. Hence, complementing the DFMA with TRIZ provides better innovative and cost-effective solutions. Examples of commercially available products that have employed additive manufacturing for building complex, graded filtering system as well as have combined the detergent filtering system with the tub are shown in Fig. 6 & 7 below.

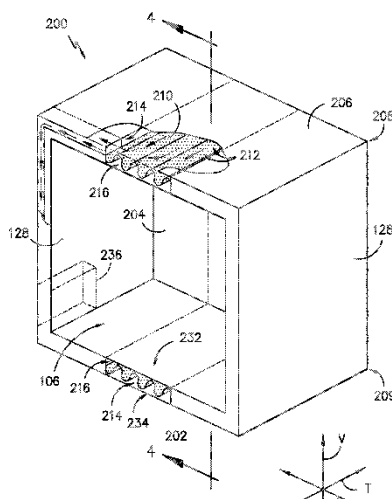


Fig. 5

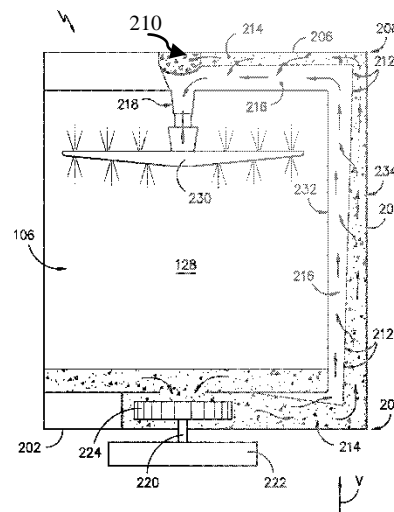


Fig. 6



Fig. 6 Complex filter shapes (dotted portions at top & bottom); Fig. 7 Unitary tub with built-in detergent filtering system (210).

**Conclusions:** In this paper authors have proposed integration of TRIZ methodology during design for additive manufacturing. These tools can act as a bridge to solve some of the unaddressed challenges in additive manufacturing such as conflicting design and functional requirements, Part consolidation and cost optimization. Authors have proposed different TRIZ tools and methodologies that can be used at every stage of design stage right from design objective to cost optimization stage. They proposed MPV analysis to understand the most critical and must be parameters in the design and delighter parameters in the design by breaking down the specific MPVs to physical parameters. Integration of MPV and parameter based modeling can enable the designer to understand the design objective and provide an uncompromising and customized design solutions. Authors have tried to illustrate these TRIZ tool mapping with current design for additive challenges taking an example of dishwasher but it can be extended to other engineering problems also.

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**Communicating Author:** [nagashiresha.g@ge.com](mailto:nagashiresha.g@ge.com)

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**TRIZfest 2018**  
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**CONTACT LENS TECHNOLOGY EVOLUTION - A STUDY OF  
CORRELATION BETWEEN PATENTS AND TRIZ TRENDS**

<sup>a</sup>Indrajit Pande, <sup>b</sup>Vinodh Mewani

<sup>a</sup>*Global Patent Operations, General Electric Company, Bangalore-560066, India*

Abstract

Technology trend may be interpreted by analysis of patent filings over the years. TRIZ based S-curve analysis is a powerful tool to provide relevant insights on the stage of evolution a given technology is in. The purpose of this paper is to study the correlation between patents filing trends and TRIZ trends based on S-curve analysis in a model technology domain of contact lenses. Once the correlation is understood, TRIZ based recommendations on probable technology focus for further development may be provided. Further, based on the technology stage understanding, directed patent searches may be done to identify advancement in specific technology subsets and new technologies which are adjacent to the primary technology focus.

Keywords: Patent, TRIZ, S-Curve, Contact lens, technology trend.

## 1. Introduction

Intellectual Property (IP) trend study has the power to reveal substantive information of a technology lifecycle. Study of “IP trends”, of a given technology segment can identify the Stage in S-curve of technology lifecycle, the given technology is in [1]. It is of interest to identify the correlation between S-curve determined by IP trend study and S-curve identified by TRIZ trend analysis. Based on the lifecycle stage of the given technology, TRIZ recommendations provide invaluable guidance on the future technology evolutions. TRIZ also helps us identify the adjacent technologies that may play role in conjunction with the given technology. In this paper, studies done on contact lens technology evolution is presented. The study determines current stage of contact lens technology, which follows typical indicators for an engineering system (ES), as expounded by GEN3® Partners [2] and correlate with the S-curve Stages (Figure 1. derived from GEN3® Partners). Further, generic TRIZ trends based recommendations for an engineering system in various evolutionary stages were followed to identify new technology patents that correlate with the prescribed evolutionary trends.

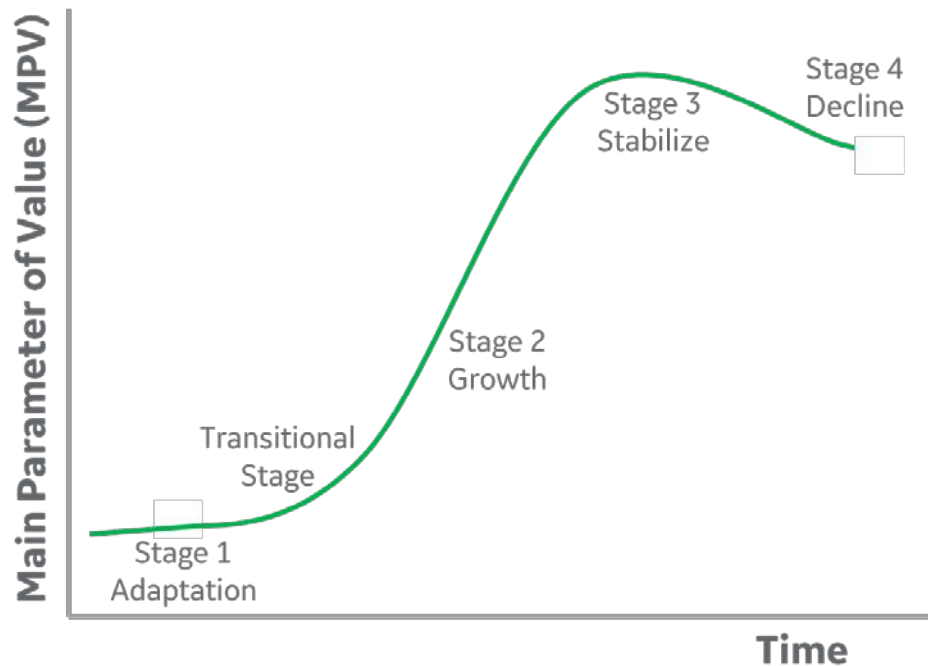


Figure 1: Typical S-curve and Stages of product life cycle

## 2. Function Analysis – Explains Evolutionary Trend

Usefulness of Function Approach for analyzing Engineering Systems and formulating and solving inventive problems has been widely demonstrated. Simon et al. presented Advanced Function Approach to further increase the effectiveness of existing methodological tools [3]. Function analysis provide supportive explanation on the changes that have taken place or changes that may be expected in future. For example, in the initial years of contact lens evolution, the lens was made of glass and was large enough to cover substantial portion of the



Figure 2: Contact lens from the 1950s (left) and from the 1990s (right) (Image by Bienengasse in Wikimedia Commons)

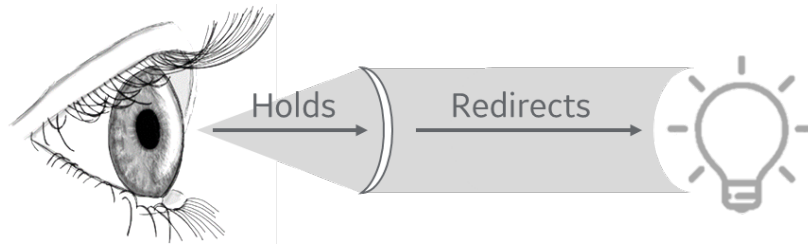


Figure 3: “Eye holds the contact lens” and “Contact lens redirects light”

eyeball. Considering the Function Model, where “Eye holds the contact lens” and “Contact lens redirects light”, for both the contact lens forms, the two statements still hold good. The contact lens was optimized during its evolution to retain the key functions and thus evolved from a large sized lenses to small lenses of modern day. There were disadvantages with the large sized lenses, they restricted eyeball contact with air or oxygen. This disadvantage was reduced with smaller lenses. To reduce the disadvantage further, the hard glass lenses gave way to plastic lenses followed by hydrogel lenses, which allow higher oxygen transmissibility. Thus, the contact lens design, construction and materials may further evolve to reduce disadvantages or add more functionality as long as the above two statements are maintained.

### 3. Patent Analysis – Trends in Technology Evolution

Citation analysis provides valuable information on technology trends [4]. Plot of cumulative number of patent citations for a given technology follows the S-curve [5]. To establish this understanding in contact lens technology, a search was conducted to identify patents in the technology domain. Search on Derwent patent database using keywords and International Patent Classification (IPC) and Cooperative Patent Classification (CPC) codes, identifies 23094 granted patents and patent applications in 5753 families. Priority year (date of filing of the first patent application) ranged between 1936 and 2017. A significant number of 4411 families of patents were from USA and European jurisdictions. In this study, data for citation analysis was restricted to these two jurisdictions. Granted US (gUS) or EP (gEP) member was picked over US (aUS) or EP (aEP) patent applications as representative family member for a given family. Preference order chosen was gUS > gEP > aUS > aEP.

Count of citing patents ranged from 0 to 916. A total of 690 patents had a count of citing patents greater than 49 with earliest priority year between 1936 and 2010. These may be considered as “High Value” patents [6]. Of them, 280 patents had a count of citing patents greater than 99. These may be

considered as “Super High Value” patents. To derive a normalized yearly citation trend, the yearly average citation number was calculated by following *Equation 1*:

$$\text{Equation 1: } \frac{C1 + C2 + C3 + \dots + Cn}{n}$$

where  $C$  is the count of citing patents for a given patent and  $n$  is the total number of patents and patent applications in the corresponding year.

Cumulative normalized average of yearly citation counts was plotted to derive the citation trend as represented by Figure 2.

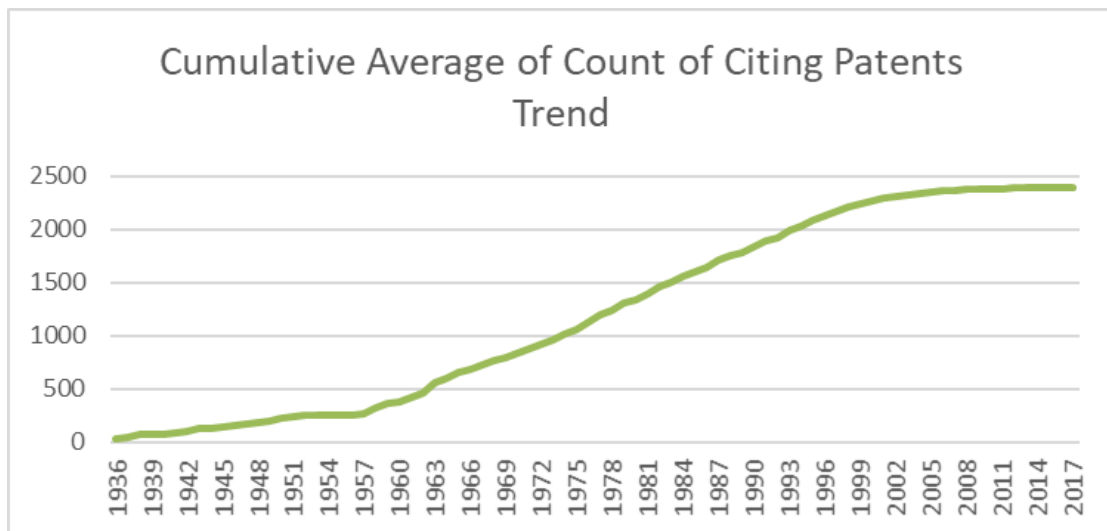


Figure 2: S-curve as determined by IP Trend based on citing patents

High Value patents were reviewed to identify technologies that correspond to various Stages in the S-curve of Figure 2. High Value patent filings prior to 1960s were related to technology improvements in the three major areas, which are, concavity of the lenses, smaller corneal lenses and lens applicator instruments. In 1963, three High Value patent filings by Otto Wichterle were identified, which were on hydrophilic plastic (HEMA) based contact lenses. Method of manufacture of these HEMA contact lenses had a high count of citing patents of 450. These filings marked the end of 1<sup>st</sup> Stage of S-curve and beginning of 2<sup>nd</sup> Stage thus identifying as the key contributors to the S-curve Transitional Stage. The other High Value patent during this Transitional Stage was on bifocal lenses. High Value patents in 2<sup>nd</sup> Stage were directly or indirectly related to the primary function of a contact lens, i.e. vision or product quality improvement. First patent identified, which referred to imparting an additional functionality to the contact lenses was from the year 1974. New function the patent described is on glucose sensing by contact lenses and count of citing patents is 361. Further, in 1978, yet another new

functionality was added to the contact lenses, which is to improve aesthetic beauty by adding colour. Patent on sustained release of medicinal dosage using contact lenses came up in 1985. In the following decade, there were tremendous improvements in contact lenses technology. For example, multifocal lenses, lenses for astigmatism correction, single use lenses, etc. were introduced primarily addressing vision improvement or user comfort. No further significant new functionalities were added until 1995. In 1995 John Weirich came up with contact lens video display technology. This was followed by two patents in 1998 describing a contact lens based camera, and semiconductor contact lens for light mediated therapy. In 2001, Hewlett Packard came up with two patents describing technologies, which include control electronics and providing power for the contact lenses. Between 2005 and 2010 there were 5 High Value patents describing technologies for contact lens based monitoring of physiological information or contact lenses with embedded electronics.

Figure 3 shows a downturn in patent filing post 2011. Data from the year 2016 onwards may be ignored as all the non-provisional filings may not be available in Derwent database.

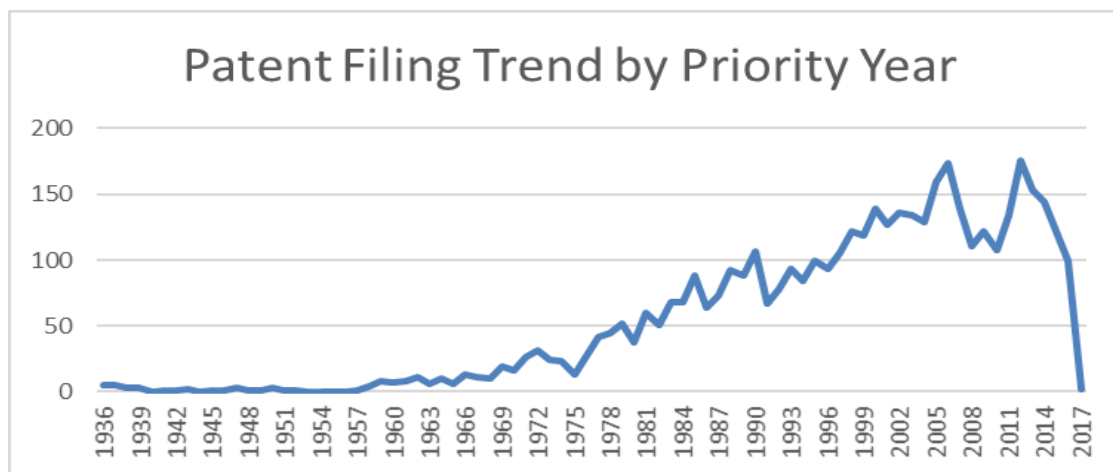


Figure 3: Patent filing trend over the years

#### 4. Technology Evolution – Open Literature Study

Evolution of contact lenses started from the year 1508 when Leonardo da Vinci first sketched the concept of contact lenses. Since then, there were several milestone events that have been recorded by many authors. Few of them are presented in Table 1.

Year	Inventor(s)	Technology
Late 1920	Sir John Herschel	Cornea molds

1929	Dr. Dallos and Istvan Komáromy	Perfected mold making
1930's		New plastics for lightweight, transparent contact lenses
1948	Kevin Tuohy	Smaller lenses: Corneal lenses – allowed long hours of usage
1950	George Butterfield	Curved instead of flat corneal lens design
1950's	Frank Dickenson, Wilhelm Sohnjes, and John Neil	Thinner lenses – 0.2 mm
1961	Otto Wichterle	Hydrophilic plastic compound (HEMA)
1963	Otto Wichterle	Spin-casting for shaping HEMA into contact lenses
1971	Bausch & Lomb	Commercial soft contact lenses
1987		Disposable soft contact lenses
1992		Tinted disposable soft contact lenses
1998	Ciba Vision	Hydrogel contact lenses

Table 1

### Some of the Key Milestones in Contact Lens Evolution

Inventions of Otto Wichterle led to the practical use of contact lenses as these were the first soft contact lenses that fitted well unlike the hard glass lenses. As technology evolved, usage of contact lenses increased. During the period between 1968 and 1983, a large number of companies evolved through acquisitions and mergers [7] and contact lens technology evolved to address better vision, comfort of use and ease of manufacture. From 1985, focus on alternate use of the contact lenses became more and more prominent. Initial focus of alternate use was to reliably detect glucose levels in blood through tear analysis. This technology development was later taken up in 2014 by Novartis and Google collaboration. This program was declared technically infeasible within next couple of years, citing inconsistent tear based readings which fluctuated with environmental conditions and did not correlate well with blood glucose readings [8]. Several other researchers and organizations are currently trying to develop the glucose monitoring technology with certain degree of success [9]. Contact lens based display is one more technology in development. A 2011 article reported on contact lenses with integrated micro-Fresnel lenses, which were tested on live rabbits [10]. A 2017 article reported that spherically curved liquid crystal display was fabricated for a smart contact lens, which may be applicable in biomedical applications [11]. These articles provide substantive indication that contact lenses are being developed for alternate applications, which are completely different from primary application of vision correction. Further, Cost indicators as shown in Table 2 (adapted from Leonard G. Schiffrin et al. [7]), indicates a downward price trend for a given class of products. The usage of contact lenses increased from 10,000-20,000 in 1960s to 125 million in 2004.



	1971-74	1975	1980	1981	1982
List price*	\$65.00	\$68.70	\$50.00	<b>\$40.00</b>	<b>\$30.00</b>
Total fitting price:*					
Ophthalmologist	\$500-600	\$250-325	\$250-300	\$250-300	\$250-300
Optometrist	300-350	400	250	225	225
Optical outlet	—	—	170	150-170	125
Large chain				120	100
Independent				178	160

Table 2: Average Soft Contact Lens List and Total Fitting Prices, per Pair

## 5. TRIZ – Correlation and Recommendations

Altshuller demonstrated that inventive activity, associated with a technological system, is closely correlated with the S-curve. Figure 4a represents S-curve for a system, Figure 4b is a typical plot of number of inventions as a function of time for an engineering system and Figure 4c represents the level of inventions (Figure 4. derived from GEN3® Partners).

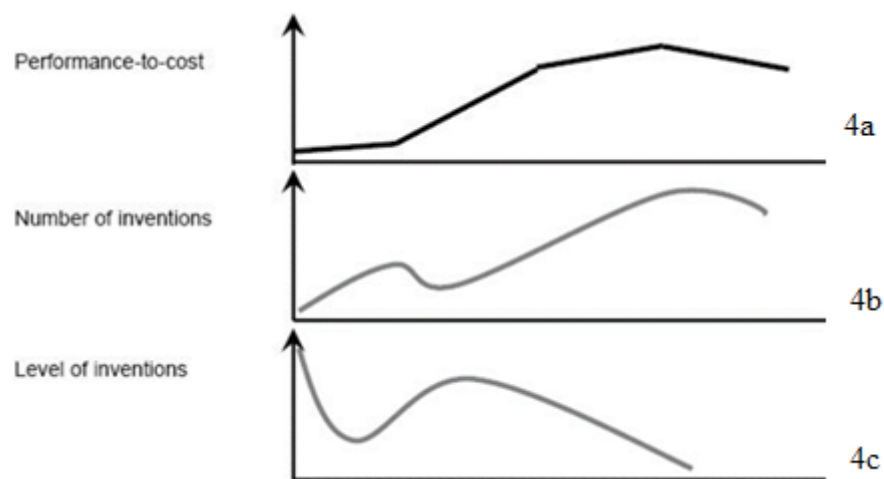


Figure 4: S-Curve and its correlation with Innovation activity

There are several indicators, which allows us to determine the particular Stage an Engineering System is in its technology or product life cycle [2]. Indicators in contact lens market and technology development were analyzed to identify the Stage in the S-curve for this technology. Identification of the Stage will allow us to evaluate the recommendations on probable future trends in contact lens technology evolution for the given Stage.

### Indicators for Stage 2:

1. Engineering System moves into mass production:

The number of contact lenses users increased since the advent of soft contact lenses and further increased upon introduction of hydrogel and disposable lenses. Mass production had already begun by 1980 and Busch & Lomb acquisition of Milton Roy Co. in 1979 and Polymer Technology Corp. in 1983 led to large scale production of soft and gas permeable contact lenses. This is in line with the 2<sup>nd</sup> Stage indicator for an Engineering System. Patent study further corroborates with the data. Otto Wichterle patent on the method of manufacture of soft contact lenses was highly cited and mass production was facilitated by his invention. This was further followed up by multiple filings on method of manufacture of various types of contact lenses.

## 2. Engineering System variations become more widely differentiated

Various types of contact lenses were in market by 1985, being sold by many companies like Bosch & Lomb, Johnson & Johnson, Revlon, Cooper Vision, Dow Corning Ophthalmic, Syntex Ophthalmic, Channel-Lombart, American Hydron, American Optical Co., Rynco Scientific, Schering-Plough, American Medical Optics, Ciba Vision Care, Danker Laboratories, Frigitronics, Alcon, etc. These contact lenses were differentiated by various technological advancements to present specific advantages over the other. This again is in line with the findings from patent analysis. Patent filings on various types of contact lenses and materials were observed. Soft lenses, disposable lenses, silicon lenses, hydrogel lenses, etc. evolved through the time period between 1970s and 1980s.

## 3. Differentiation between Engineering System's applications increases

Apart from the patent filings on contact lenses technologies for vision correction, patents for medicine delivery, glucose monitoring by tear analysis, video display on lens, lens based camera etc. were also filed from 1974 onwards. New applications were constantly being added to the contact lenses, though they were mostly in initial developmental stage.

## 4. Supersystem elements start adapting to Engineering system

Patent filings in 1980s on contact lens storage, blister packaging for disposable lenses, cleaning systems, specialized cleaning fluids, lens coatings, lens applicators, etc. were identified, which corroborates with the 2<sup>nd</sup> Stage Engineering System Indicators.

## 5. Modification slows and becomes less varied toward the end of the stage

In the 1980s, several patents were filed with focus on incremental advancements on the contact lenses for vision improvement or lens quality.

These indicators clearly provide adequate information that contact lens technology was in 2<sup>nd</sup> Stage of the S-curve in the 1980s. To determine whether contact lens technology and industry is in Stage 3 of technology life cycle, indicators for Stage 3 were analyzed.

### Indicators for Stage 3:

#### 1. MPVs change slowly:

Soft lenses or disposable lenses are in the market for past three decades. Except for incremental changes, there is rarely any technological advancement that has taken place between the contact lenses that were available thirty years ago and today. Neither many new players are entering into the market to offer new technologies in contact lenses for vision correction. Patent filing in recent years, focus on new materials for incremental improvement or optimized production of the contact lenses.

#### 2. The Engineering System acquires functions that are of little relevance to the main function

Several new technologies that are being developed for past decade involving contact lenses are not related to improving vision. Non-invasive glucose monitoring, contact lens based display or medicine delivery are technologies that are in focus among several technology giants like Google. Neither the technology or the company focuses on vision correction or improvement.

#### 3. The Engineering System consumes highly specialized resources

New technology development requires resources that were not important for the primary role of a contact lens. For example, PCBs or sensors or powering devices that are Specially modified to be included in the contact lenses for imaging or display applications. Patents in this alternate technology segments are being filed in recent years for contact lens applications. These are clear indications of the contact lens technology is already in 3<sup>rd</sup> Stage for product life cycle.

#### 4. The Engineering System has reached some development limits

As indicated earlier, significant improvements of contact lens technology for vision correction are not taking place in past decade or more. Improvements or changes that are apparently being brought into the products are merely incremental indicating some development limits has been reached.

Thus, it is clear, contact lens technology is in Stage 3 of its technology life cycle. When Stage 4 indicators were analyzed, most of the indicators did not match with the current market and technology indicators for contact lenses.

## Recommendations for Stage 3:

1. Near- & medium-term: reduce costs, develop service subsystems, improve design

Cost reduction is critical to keep the product value high and relevant. More and more contact lens users are opting for disposable lenses. There are several options and packages that are being provided by various retailers to suit customer needs. Monthly packages, quarterly packages or even daily packages of disposable lenses are being offered, a concept which is in line with the recommendations provided by TRIZ. Customization to cater to customer needs is the order of the day. Aesthetics and utility are being combined to provide to the customer need and preferences. Contact lens industry may look into opportunities in customer centric customized products.

2. Long-term: switch principle of action for the Engineering System or its components

Switching principle of action and removing key drawbacks of the existing system is a recommendation that may lead to a jump to another S-curve and another product life cycle. It will need resources to identify alternate ways of vision correction. A probable example may be, laser based cornea modification for vision correction. Alternate technology may also be considered which allows refractive index modulation without use of contact lenses.

3. Transition to the supersystem – deep trimming, integration of alternative systems – is highly effective

Deep trimming to transfer the function of a contact lens to supersystem may be effective. Laser based correction is probably a step in line with this recommendation. Cornea modification to refocus the incident light onto the retina is already being carried out. One limitation of the technology is, this form of vision correction depends on the thickness of the cornea. It may be worthwhile to explore any opportunity where requirement of cornea thickness can be eliminated.

4. Look for an MPV to develop that is at an earlier stage

Identification of an MPV which is at an earlier stage may help refocus on the improvement of the contact lenses to increase technology value. This may open up new technology development avenues.

## 6. Conclusions

In this paper, we have reviewed the correlation of patent filings with product lifecycle in a model technology domain. Citation analysis and patent filing trend can provide valuable clues to identify the Stage, a given product is, in its life cycle. A combination of TRIZ based study and patent analysis can provide recommendations that can help us plan on future technology research and upgrades for the product to stay relevant in the market. Based on GEN3® Partners TRIZ S-curve methodology, we have reviewed the recommendations for further growth of contact lens industry. It is clear that contact lens technology for vision improvement is in 3<sup>rd</sup> Stage of technology lifecycle. TRIZ based recommendations for the product improvement the industry should focus at this Stage are provided. Some of these recommendations are already being partially implemented in the industry. Firstly, service models need to be developed for this technology segment which takes care of individual customer needs and preferences. Secondly, new and useful functionalities may be added, which are of day to day use. Technology development in adjacent areas related to vision needs to be considered for the long run. Opportunities in contact lens based display, imaging, sharing of information, health monitoring along with vision improvement needs to be explored. Finally, research needs to be focused on supporting engineering systems to develop highly specialized resources to enable new contact lens based technologies, for example, flexible electronics and sensors, invisible electronics, low footprint battery, alternate source for energy harvesting, etc. that may be embedded into the smart contact lenses.

“Knowing where the system is now and being aware of statistically proven trends of evolution, we can always outline probable directions” – Sergei Ikonenko.

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**INNOVATION FUNNEL OF MODERN TRIZ: EXPERIMENTAL  
STUDY TO SHOW THE EFFICACY OF THE TRIZ-ASSISTED  
STAGE-GATE PROCESS**

Oleg Y. Abramov<sup>a</sup>, Sergey A. Markosov<sup>a</sup>, Alexander V. Medvedev<sup>a</sup>, Vladimir Y. Rychagov<sup>a</sup>

<sup>a</sup>*Algorithm Ltd., 16 Ruzovskaya Street, St. Petersburg, 190013, Russia*

**Abstract**

It is widely acknowledged that today's innovation processes are generally inefficient: various sources indicate that only one out of three-thousand, raw ideas yield a commercial product. Most of the ideas are quickly rejected before much time or money is spent on their development. Those that remain, some 300 raw ideas, are typically selected for further investigation and development, which results in launching around 125 small pilot projects and other time and money-consuming activities – all for the sake of a single commercially successful product. TRIZ-consultants claim a much higher efficacy with the TRIZ-based innovation process because TRIZ provides a more systematic basis for innovation and greatly speeds up the new product development (NPD) process. Unfortunately, so far, there is no solid quantitative data available to support this statement. In this paper, the authors have tried to evaluate the effectiveness of modern TRIZ in NPD by analyzing a pool of technical solutions for new products developed for different companies in actual TRIZ-consulting projects. For each solution, the authors have tried to identify whether the new product was ultimately launched. This analysis revealed (1) the number of solutions/ideas that TRIZ consultants developed in order to launch one new product and (2) the percentage of successful projects. The results show that using TRIZ indeed helps to improve the efficacy of the NPD process from 5 to 15 times, which confirms that TRIZ brings high value to NPD.

Keywords: innovation funnel, NPD, TRIZ

**1. Introduction and problem statement**

It is widely acknowledged that today's innovation process is not very efficient in terms of business impact. For example, Stevens and Burley in their extensively cited article [1] indicate that in order to obtain one commercially successful product about 3000 raw ideas are typically generated. Almost all of these ideas are then rejected in the new product development (NPD) process.

The innovation funnel described by Stevens and Burley [1] includes the following steps:

- About 3000 raw ideas are generated and internally screened,
- Approximately 300 of these ideas are then submitted to decision makers,
- About 125 ideas are further developed in small-scale projects,
- On average, only 1.7 of those ideas result in product launch,
- Just one of the launched products is commercially successful.

Other authors indicate similar numbers characterizing the innovation funnel. For example, Staube in his post [2] indicates that 95 projects aimed at incremental innovations result in launching just

one product (which is not necessarily commercially successful). Staube's figures are nearly comparable to Stevens and Burley's data that 125 small-scale projects yield 1.7 launched products.

In some industries, the efficacy of innovation is even lower than that indicated by Stevens and Burley. For instance, in the pharmaceutical industry the innovation funnel is especially inefficient: as Torjesen indicated in her article [3], "for every 25,000 compounds that start in the laboratory, 25 are tested in humans, 5 make it to market and just one recoups what was invested."

In order to improve the success rate of the innovation process, Yoram [4] suggested using a diversified team rather than a single purely technical inventor to generate, screen and present ideas to top management. This should lead to generating fewer bad ideas and rejecting fewer good ideas in an NPD process.

The common perception, though, is that in order to increase the probability of obtaining a commercially successful product it is necessary to generate more ideas, the more the better. For example:

- In Design Thinking, as indicated by Dam and Siang [5], "the goal is to generate a large number of ideas — ideas that potentially inspire newer, better ideas — that the team can then cut down into the best, most practical and innovative ones."
- The Systematic Inventive Thinking (SIT) approach by Boyd and Goldenberg [6] is based on generating a multitude of creative ideas 'inside the box' because "...the density of creative ideas is higher inside than outside."

TRIZ, being an efficient methodology for systematic problem solving, offers a different way to improve the efficacy of the NPD process: generate fewer ideas, but better and more targeted ideas as provided by the TRIZ-assisted Stage-Gate process [7]. The efficacy of TRIZ as problem solving and problem finding tools is confirmed in numerous papers, for example by Filmore and Thomond [8], Harlim and Belski [9], etc.

Many case studies illustrating TRIZ effectiveness have been published [10 -13]. The case studies, however, represent only anecdotal data that illustrate how useful TRIZ is in solving technical problems, but do not disclose whether the solutions obtained using TRIZ yielded commercially successful products. This leaves room for some scepticism and questions about the effectiveness of TRIZ in terms of business impact.

An example of such scepticism can be found in the report by Ilevbare, Phaal, Probert, et al. [14] who clearly expressed a common attitude toward TRIZ: "it appears to pay little attention to linking the inventive problems and their solutions to market needs and drivers. Therefore there exists the unpleasant possibility of TRIZ providing a solution to a problem which has little or no profitability or commercial benefit to an organization." It should be said that this statement seems to be relevant for the older, "classical" TRIZ that utilizes only Altshuller's Contradiction Matrix, SU-Field Analysis, ARIZ, etc.

On the other hand, modern TRIZ has tools such as Voice of the Product (VOP) [15] and Main Parameters of Value (MPV) Analysis [16,17] to address business needs better. Therefore, TRIZ developers and practitioners, including the authors of this paper, claim that modern TRIZ demonstrates very high efficacy in NPD, which is supported by case studies described in a few conference papers [15,17,18]. However, there is no solid quantitative data to back up this anecdotal evidence.

In this paper, the authors try to fill this gap by deriving quantitative data on the effectiveness of the modern TRIZ innovation funnel and contrast it to that described by Stevens and Burley [1].



## 2. Method

In order to determine the modern TRIZ innovation funnel, the authors statistically analyzed the outcomes of a wide range of actual TRIZ-consulting projects in which the authors were involved.

The analysis includes the following steps:

1. Out of a pool of completed projects, only those aimed at NPD or at developing/improving a new technology for manufacturing an existing product were selected for further analysis. Projects that were a continuation of some previous project and aimed at developing the same product were not counted.
2. The outcomes of each selected project were identified: (1) how many solutions/ideas were submitted to the client after the problem solving stage of the project; (2) how many solutions were further developed (e.g. substantiation, prototyping or patenting efforts); (3) whether any of these solutions eventually yielded a launched product; (4) whether any of these solutions were rejected by the client.
3. Percentages of “successful” solutions and projects (those that yielded launched products) were calculated.

The following comments regarding this procedure should be noted:

- The number of raw ideas generated in each project could not be identified because (1) the TRIZ-based methodology used in these projects does not assume using brainstorming, SIT or other techniques for generating raw ideas, and therefore (2) raw ideas that were randomly generated in the projects were not documented.
- Since all of the projects analyzed are small (typically 8-12 weeks), they can be considered equivalent to the ‘small projects’ in Stevens and Burley’s innovation funnel.
- It was not possible to identify just how many of the launched products were commercially successful because this is sensitive information that clients are not always willing to share.

## 3. Results

In this research the authors analyzed a pool of 206 TRIZ-consulting projects in which they were engaged from 1994 through 2017. All of these projects were performed for different clients/companies representing a wide variety of industries. In all projects the TRIZ-assisted Stage-Gate process [7,18] was employed.

From this pool, 161 ideation projects where the objective was to solve a specific technical problem were extracted for further analysis. All other types of projects (e.g. IP landscaping, patent circumventions, and feasibility study projects) were excluded from consideration.

The projects analyzed have, in total, yielded 1082 feasible technical solutions that were delivered to the clients after the problem solving stage.

Only 180 of these solutions were selected by the clients and further developed at the substantiation stage of the projects, which means that some ‘small efforts’ were put into them (e.g. computer simulation, proof-of-principle prototyping, or patenting were done).

Of this number, the authors were only able to trace what happened with 64 solutions because often clients did not give feedback on whether the solutions delivered to them were actually implemented. Therefore, the authors analyzed only these 64 solutions, including:

- 48 solutions aimed at developing a new product; and 16 solutions aimed at improving a manufacturing technology or equipment;

- 31 successful solutions, i.e. they were actually implemented in launched products, and 33 unsuccessful solutions; that is, they were either abandoned by the clients or the clients tried to implement them, but did not succeed.

Table 1 summarizes the result of this effort.

Table 1

Modern TRIZ innovation funnel revealed in this research is compared to Stevens and Burley data [1]

Item	Data derived in this research	Stevens and Burley data
TRIZ-consulting projects	161	N/A
Submitted ideas	1082	300
Small efforts (e.g. prototyping) / patent submissions	180	125
Launched products	31	1.7

As can be seen from Table 1, the innovation funnel of modern TRIZ is much more efficient than the regular innovation funnel used in industry. This can be characterized by the success rate at different NPD stages, i.e. by the percentage of submitted ideas and solutions invested with some 'small effort' that resulted in launched products.

Fig. 1 shows the calculated success rate of different NPD steps and the success rate of TRIZ-consulting projects in general.

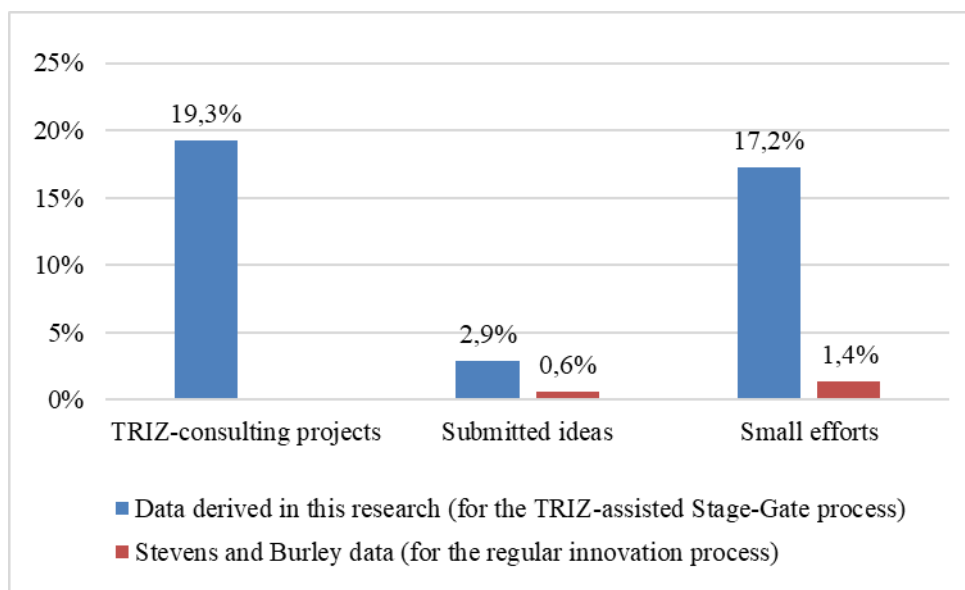


Fig. 1. Success rate at different NPD stages (calculated using the data from Table 1)

## 4. Discussion

As can be seen from Fig.1, the modern TRIZ applied in the TRIZ-assisted Stage-Gate process provides, by an order of magnitude, a more efficient innovation funnel in terms of the number of small efforts that are needed in order to launch one product.

It should be noted, however, that the results of many projects analyzed in this research are not known to the authors. Therefore, there is a possibility that some solutions resulting from these projects have, in fact, been implemented by the clients or their implementation is still in progress, which may be quite likely for recent projects. This means that the number of successful solutions

and successful projects may be higher than estimated in this paper. Therefore, the effectiveness of TRIZ indicated in this paper should be considered as a ‘pessimistic estimation’ while the actual effectiveness of modern TRIZ may be much higher.

In addition, it is important to note that all solutions, including those rejected by clients, were substantiated and proven technically feasible at the end of each analyzed project. The clients appreciated and accepted all of these solutions but later rejected some of them for non-technical reasons.

As shown by the authors in a recent paper [19], while clients rejected some solutions due to the ‘human factor’, most solutions were rejected because they were unpromising in terms of business impact. Such solutions could have been rejected early in the project by the TRIZ team if a new TRIZ tool ‘QEA-based screening’ [20] had been employed. Thus, the authors believe that using this tool may further increase the effectiveness of modern TRIZ.

## 5. Conclusions

The results presented in this paper show that the effectiveness of modern TRIZ in the TRIZ-assisted Stage-Gate NPD process is by at least an order of magnitude higher than the regular innovation process, and about 20% of TRIZ-consulting projects result in a launched product (pessimistic estimation).

The new TRIZ tool ‘QEA-based screening’ may help to reduce the number of generated technical solutions that are unpromising businesswise, thus further increasing the effectiveness of modern TRIZ and the success rate of TRIZ-consulting projects.

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**Communicating Author:** Oleg.Abramov@algo-spb.com

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**SU-FIELD ANALYSIS IN OPTICS: RESEARCH AND PRACTICE**

Pavel Fimin<sup>a</sup>, Vladimir Rychagov<sup>a</sup>

<sup>a</sup>*Algorithm Ltd., St. Petersburg, 190013, Russia*

**Abstract**

This paper focuses on the employment of Substance-Field (Su-Field) analysis for solving theoretical and practical problems in the field of optics. The main goal of the work is to review the features of the transition from a Su-Field model describing the initial situation to the invention standards and further to appropriate optical effects implicitly contained in the standard solutions for solving the inventive problem. Case studies related to synthesis and destruction of optical Su-Fields have been considered. Su-Field models of the following optical problems have been proposed: (1) enhancement of amplitude/phase contrast for visualizing concealed or hard-to-detect objects, (2) facilitation of effective physical or chemical interaction of substances with each other using the light field with specified characteristics, (3) neutralization or attenuation of undesirable light flux that propagates through optical components together with useful light flux. The application of phenomena of the light self-action and optical phase conjugation for the instrumental implementations of the invention standards is discussed.

Keywords: TRIZ, Su-Field analysis, substance, field, inventive standards, optical effects and phenomena.

**1. Introduction**

The concept of a Substance-Field (Su-Field) as a minimal operable technical system is one of foundation stones of TRIZ [1]. The Su-Field describes a technical system in terms of substances, fields and physical interaction between substances and fields. In order to improve the technical system, it is necessary to build and reconstruct its Su-Field model using certain rules that in TRIZ are named standard inventive solutions, or inventive standards. Altshuller called the inventive standards ‘destroyers of technical and physical contradictions’ [2].

Recommendations formulated in the standard inventive solutions are universal in nature [3]. However, for addressing practical tasks there is need not only to know the inventive standards, but also to be able to find physical, chemical, biological and other effects implicitly contained in these standard solutions. Meanwhile, in literature on TRIZ, a task of the transition from the Su-Field model and inventive standards to appropriate effects is discussed clearly insufficient.

This work focuses on the application of Su-Field analysis for solving theoretical and practical problems in the field of optics. The paper topic seems to us relevant. The point is that in optics it has often dealing with the modification of fields, rather than substances. Therefore, elementary optical Su-Field<sup>1</sup> can involve not only two substances and a field, as is customary in classical TRIZ, but also two fields and a substance [4, 5]. These Su-Fields are studied in TRIZ in less detail.

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<sup>1</sup> The term ‘optical Su-Field’ refers to the Su-Field that contains at least one optical field. At that, to optical fields in TRIZ relate not only visible light, but also infrared and ultraviolet radiation as well as X-rays.

Section 2 of the paper reviews problems related to synthesis of optical Su-Fields. It is shown (1) how the addition of missing substances and/or fields in accordance with the inventive standards of subclass 1.1 allows visualizing hidden or hard-to-detect objects and (2) how the light field with specified characteristics provides effective physical or chemical interaction of substances with each other. In Section 3, optical problems pertinent to destruction of Su-Fields are presented. Application features of the standards of subclass 1.2 to optical Su-Fields are explained. Solutions, in which neutralization or attenuation of harmful light flux is performed due to the light self-action are concisely reported. The operation of optical phase conjugation for the instrumental implementation of the inventive standard 2.3.2 “Matching the rhythms of fields” is discussed.

In this paper, we will use the notations accepted in classical literature on Su-Field analysis [1, 2]. Substances and fields will be labeled with capital letters S and F respectively. Action of one element on the other or interaction of elements with each other we will depict by lines with arrows that point direction of action. Useful relationships between elements will be shown by straight lines. Wavy lines will indicate harmful relationships. For useful actions or interactions that are performed ineffective, we will utilize dotted lines.

## 2. Synthesis of Optical Su-Fields

In this Section, problems related to the synthesis of optical Su-Fields are considered. As consistent with the inventive standards of subclass 1.1 the missing components (substances and/or fields) are introduced to the incomplete Su-Field system to make it complete.

### 2.1. How to See the Invisible

Dental caries is the most common chronic diseases of people worldwide. An estimated 3.9 billion people – over half the total population suffer from tooth decay [6]. It is known that caries is caused by pathogenic bacteria, which form dental plaque on the teeth [7]. Dental plaque cannot be flushed away by simply rinsing with water. Moreover, the plaque biofilm is transparent and therefore not readily visible, particularly to one who is not skilled in its identification. How to detect where plaque has settled on the teeth and which tooth sites need to be cleaned more thoroughly during oral hygiene procedures?

A schematic description of the plaque detection problem is presented on the left-hand side of Fig. 1. There is not a Su-Field: we have only a substance  $S_1$  (dental plaque), which exhibits a low absorptance in visual spectral range, and weak signal field  $F_1$  generated by the substance  $S_1$ . In order to amplify optical signal  $F_1$ , let us add the second substance – a coloring agent or dye with the high absorptivity [8, 9]. The completed optical Su-Field is shown in Fig. 1 to the right. The disclosing agent  $S_2$  attached on the plaque film  $S_1$  makes the plaque visually distinguishable from the remainder of the tooth surface.

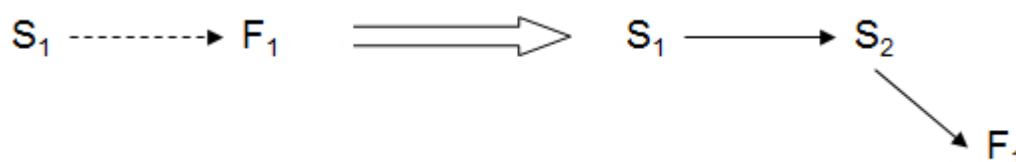


Fig. 1. Synthesis of the optical Su-Field. In order to amplify signal  $F_1$  reflected from the hard-to-detect object  $S_1$  (dental plaque), the substance  $S_2$  (the coloring agent or dye with the high absorptivity) is added

A transition to a bi-system in accordance with the inventive standards of subclass 3.1 is embodied in [10], where a two-tone plaque-disclosing composition has been suggested. The pink dye (phloxin B) adheres to all plaque, whereas the blue dye (FDA Blue 1) diffuses more easily into the

denser/thicker plaque. Therefore, ‘fresh’ and ‘old’ plaque can be distinguished: ‘fresh’ plaque stains pink while ‘old’ plaque stains blue-purple.

Not only amplitude, but also phase contrast can be enhanced by the addition of a new substance. For instance, conventional X-ray attenuation leads to poor image quality if the sample is weakly absorbing (Fig. 2, left-hand side). In X-ray phase-contrast imaging technique, local differences in speed of wave propagation through different objects are taken into account<sup>1</sup>. In TRIZ, this means that the X-ray Su-Field is made complete by the addition of the phase-sensitive component  $S_2$ , which picks up local phase distortions of the X-ray beam (field  $F_1$ ) passed through the object  $S_1$ . These phase differences are then converted into corresponding changes in amplitude that can be distinguished (see Fig. 2, right-hand side).



Fig. 2. Su-Field model describing X-ray phase-contrast imaging technique. Conventional X-ray attenuation leads to poor image quality when the sample  $S_1$  is weakly absorbing. In order to enhance image contrast, local phase distortions of the X-ray beam (field  $F_1$ ) passed through the object  $S_1$  are detected by the phase-sensitive component  $S_2$ . Phase differences are then converted into corresponding changes in amplitude that can be distinguished

For experimental realization of X-ray phase-contrast imaging, several methods have been developed: crystal interferometry, grating imaging, edge illumination, etc. For details, see review [14] and references therein.

Now let us try to solve the problem of contaminant detection in a powdered pigment [15]. Again, as in the previous examples, the initial situation is depicted by the incomplete Su-Field. Just this once, that comprises a substance  $S_1$  (pigment) and a hard-to-see signal  $F_1$  carrying information on impurities in the sample. In order to complete the optical Su-Field, a clear liquid  $S_2$ , refractive index of which is matched with refractive index of the pigment, is added to the powder  $S_1$  and then the light beam (field  $F_{IN}$ ) is impinged to the suspension  $S_1$ - $S_2$  (Fig. 3).

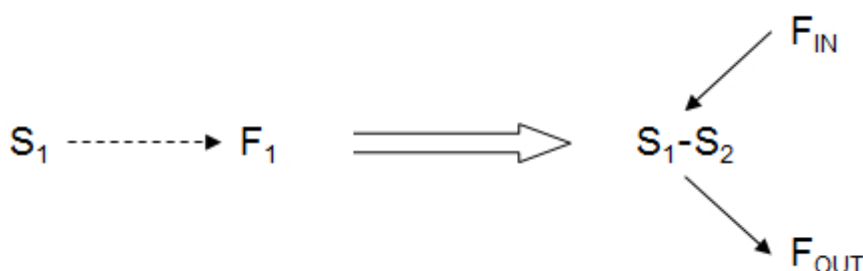


Fig. 3. Synthesis of the optical Su-Field. For the contaminant detection in the powdered pigment  $S_1$ , a clear liquid  $S_2$ , refractive index of which is matched with refractive index of the pigment, is added and then the light beam  $F_{IN}$  is impinged to the suspension  $S_1$ - $S_2$ . Impurity content in the initial powder is measured by radiation intensity of the light beam  $F_{OUT}$  transmitted through the suspension

Such a choice of the liquid  $S_2$ , in which the powder  $S_1$  is immersed, relies on the characteristic light dispersion of materials. In case of the pure pigment, suspension  $S_1$ - $S_2$  is relatively transparent

<sup>1</sup> Of course, the phase-contrast imaging technique can be applied to the whole optical range of wavelengths rather than only to X-rays [11-13].

and, consequently, light beam  $F_{OUT}$  transmitted through the suspension gains a maximum value. Impurities with refractive index different from that of the host liquid scatter radiation  $F_{IN}$ , thereby revealing themselves. Furthermore, the lower intensity of the transmitted beam  $F_{OUT}$ , the higher impurity content in the initial powder<sup>1</sup>.

How to detect a coolant leakage in a refrigerating unit? This case study has been analyzed by Altshuller [1, 2]. In order to make the Su-Field complete (see Fig. 4), a small amount of fluorescent dye (substance  $S_2$ ) is added to a coolant (substance  $S_1$ ) and then the assumed leakage area is exposed to ultraviolet radiation (field  $F_{UV}$ ). At that, even the smallest droplet of the coolant, if it has leaked, will glow (i.e. field  $F_V$  of the bright visible light will be emitted). Working liquid and technical system as a whole can be manifold: water in a boiler, fuel, oil or hydraulic fluid in an automobile, etc. In all cases, the Su-Field solution has the same form<sup>2</sup>.

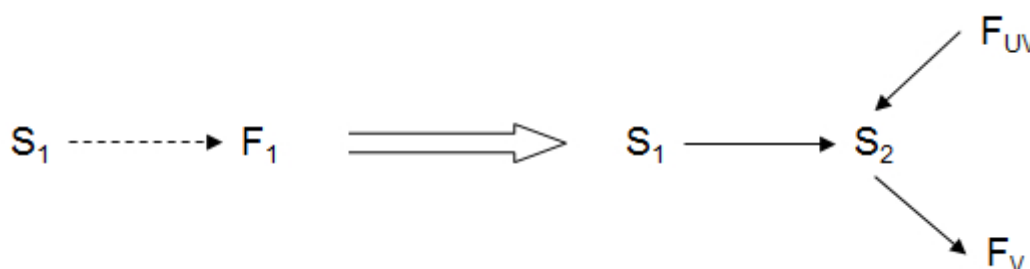


Fig. 4. Synthesis of the optical Su-Field. For the leakage detection, fluorescent dye  $S_2$  is added to working liquid  $S_1$  and the assumed leakage area is exposed to ultraviolet radiation (field  $F_{UV}$ ). Leaks will glow (visible light  $F_V$  will be generated)

Another group of substances, that enable to see the invisible, represent photochromic materials. Their capability to change optical properties under exposure to the ultraviolet light is widely used in anti-counterfeiting technologies [17]. For example, in [18], the photochromic dye is added to the ordinary colorant to make an authentication mark. The suggested photochromic dye is colorless in the visible light and becomes visible after it has been exposed to ultraviolet radiation. As a result, initial color of the mark is temporary changed. If a counterfeiter merely reproduces the marking with a standard dye of the same color as that of the non-photochromic pigment, his counterfeiting action will be easily detectable because after illumination with the ultraviolet light the authentication mark will not change its color.

Substances added to make a Su-Field complete can also change their optical properties under the action of non-optical fields. In [19], a coating composition for non-destructive flaw testing the aircraft panels is proposed. That comprises materials sensitive to both ultraviolet radiation and heat exposure. To the panels that are bonded together, the coating composition is applied and then the ultraviolet light is used to change initial color of the coating. After that, the thermal field is applied to heat the panels to a temperature in the range of 30 to 50°C. If flaws are present between layers due to poor bonding, heat will not be readily removed from those areas. The build-up of heat at the surface of areas with the imperfections causes the dye to revert to its original color.

<sup>1</sup> The light dispersion method can be used for on-site testing purposes where the speed, simplicity and cost of measuring are an issue.

<sup>2</sup> Luminophores act as follows. The excitation with light of a specific wavelength brings electrons of molecules of a luminophore from a ground state to an excited state. These electrons release this acquired energy rapidly by emitting light. Since a small amount of energy is lost due to non-radiative relaxation, the emitted light has lower energy and therefore a longer wavelength than the wavelength of excitation [16].



In smart diapers presented by Roe et al. [20], the coloring agent in a powdered form is adhered to an absorbent pad. This coloring agent is triggered by waste liquid from an infant. That gives a convenient visible indication of used condition and readiness for discard the diaper without being manually checked it several times. Thus, the chemical field is here used to make the optical Su-Field complete.

Solutions that do not require the addition of new substances are particularly valuable. In them, the optical Su-Field synthesis is putted into effect by the excitation of the existing substance with the impinging field.

Suppose that we need to detect which side of float window glass has been in contact with the molten tin during manufacture<sup>1</sup>. It is necessary when glass surfaces are further functionalized to produce glass bonds, for glass adhesion or for coating application. Our resource is tin atoms themselves, which have diffused into the glass surface layer from the tin bath. Milky bluish-grey fluorescence is appeared if the tin side is directly illuminated with the ultraviolet light (Fig. 5). When the opposite side of the glass sheet is irradiated, the ultraviolet light is absorbed by the glass bulk and no fluorescence can be detected [23].

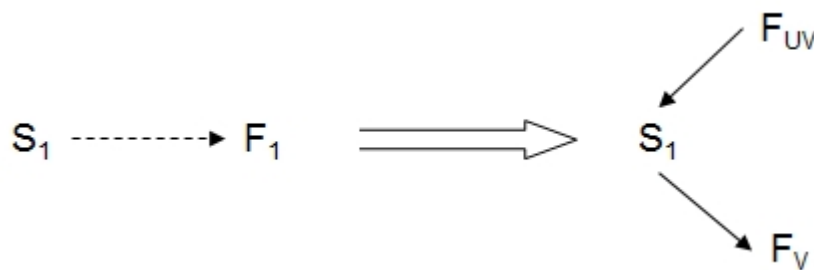


Fig. 5. Synthesis of the optical Su-Field using a field that excites an initial substance. If the tin side of a float glass sample  $S_1$  is directly illuminated with the ultraviolet light (field  $F_{UV}$ ) visible light fluorescence (field  $F_V$ ) is appeared

Next problem relates to visualization of concealed objects under clothes, in bags, or through other light obstructing barriers. As described by Lev and Sfez [24], remote optical detection of objects behind opaque materials can be provided by the combination of ultrasound and laser beams. The built acousto-optical Su-Field is shown in Fig. 6.

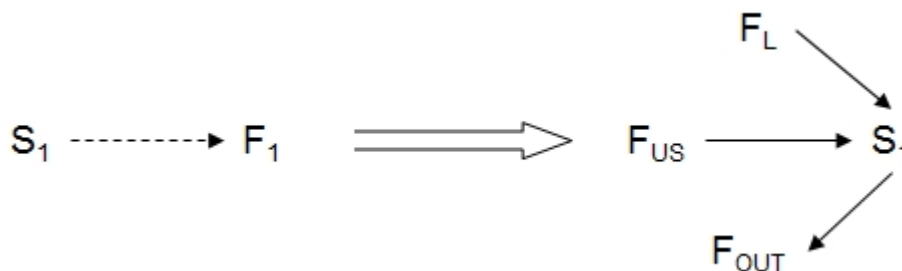


Fig. 6. Synthesis of the acousto-optical Su-Field. In order to detect the concealed object  $S_1$  behind the light opaque barrier, the combination of ultrasound waves (field  $F_{US}$ ) and laser radiation (field  $F_L$ ) is applied

Ultrasound waves (field  $F_{US}$ ) penetrate a light-impermeable fabric and are reflected by the human body and hidden objects (substance  $S_1$ ). The reflected signal makes the outer surface of the cloth vibrate at the ultrasonic frequency. A non-uniform acoustic pattern is formed due to a difference in the acoustic impedance between the human body and concealed objects. In turn, laser radiation

<sup>1</sup> See Chapter 5 in monograph [21] and lecture [22] for details on float glass production.

(field  $F_L$ ) generates on the vibrated surface of the fabric a dynamic speckle (field  $F_{OUT}$ ) related to the acoustic pattern. In this manner, the analysis of the laser speckle created at the outer surface of the cloth allows receiving information on shape and dimensions of concealed objects beneath the light opaque screens.

The case studies considered in this subsection are lumped together by one problem situation: how to visualize a concealed or hard-to-detect object. Therefore, a good alternative approach for dealing with these problems is the synthesis and forcing of the measuring Su-Fields using the inventive standards of subclasses 4.2 and 4.3. The said standards prescribe to introduce missing substances and/or fields, application of physical effects, using resonance oscillation of a detected or attached object, etc.

## 2.2. Joining Assisted by the Field

Let us take two substances:  $S_1$  and  $S_2$  and set ourselves a task to make a chemical interaction between them. In order for a chemical reaction to occur, it is necessary to overcome repulsion of electron shells of interacting molecules, break or weaken interatomic bonds in molecules of initial reagents [25]. For this purpose, a certain amount of energy has to be spent: kinetic energy of colliding particles may be insufficient to form a new substance. General solution is displayed in Fig. 7. We make the Su-Field complete supplying activation energy to molecules of reagents  $S_1$  and  $S_2$  by a field  $F$ .

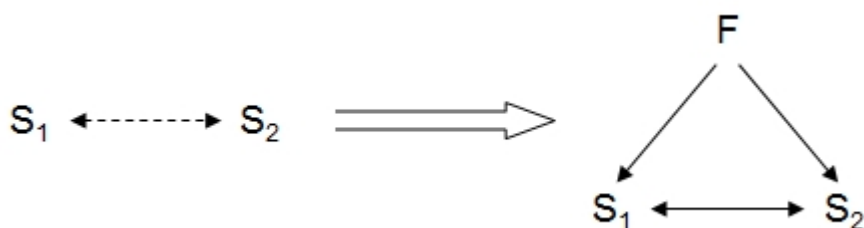


Fig. 7. Activation of a chemical reaction between substances  $S_1$  and  $S_2$  by a field  $F$

The field  $F$  can be thermal; however, rise of temperature activates a large number of various chemical processes that can be undesirable for a reaction to occur. This situation is imaged on the Su-Field model presented in Fig. 8 to the left. Replacement of the thermal field  $F_T$  with the more controllable light field  $F_{LIGHT}$ , as shown on the right-hand side of Fig. 8, allows energizing only those bonds, which are necessary for a chemical reaction. It is possible, since different covalent bonds in a molecule oscillate at different optical frequencies. By selecting a light wave with the specified oscillation frequency, we can “shake” the desired bond.

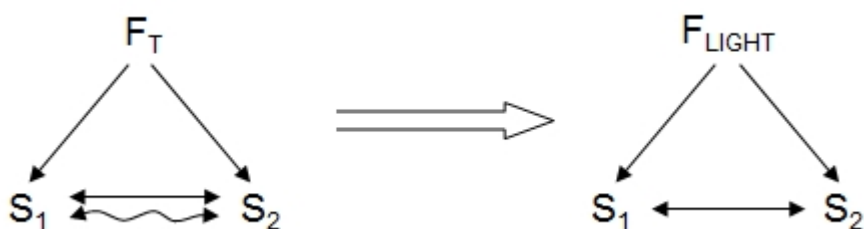


Fig. 8. Replacement of the thermal field  $F_T$  for activation of a chemical reaction between substances  $S_1$  and  $S_2$  with the more controllable light field  $F_{LIGHT}$

For the first time acceleration of the intermolecular reaction by selective excitation of oscillations of individual bonds in a molecule demonstrated German chemists from the Free University of Berlin [26]. The formation of urethanes from isocyanates and alicyclic alcohols was studied. Under the influence of ultrashort laser pulses exciting oscillations of the O–H bond in the molecule of alcohol, an increase of the reaction rate up to 24% has been observed. Researchers note that the

source of acceleration reaction could not be laser-induced heating initial reagents, since no change in temperature was recorded during the reaction.

Now let us imagine that substances  $S_1$  and  $S_2$  are construction materials and our purpose is to join them together. The same Su-Field model is used for the problem solving. Optical Su-Field can be built by supplying high-intensity radiation from a laser [27] or a discharge lamp [28] in the narrow joining area of the details. That provides the selective maximum regime of a field exposure on the substance as required by the inventive standard 1.1.8. Moreover, as proposed by Gradl et al. [29], dynamical focusing system can be implemented to vary the beam spot size. Thereby, control of the welding regime is realized in accordance with the standard 2.2.4.

### 3. Destruction of Optical Su-Fields

In many optical applications, it is required to neutralize or weaken the light exposure on a substance, eliminate undesirable effects that result in deterioration of optical performance of a technical system. Most of these tasks are solved with the help of the inventive standards 1.2.1 and 1.2.2, in which elimination of harmful action is carried out by introduction of a new substance or by the modification of existing substances [2]. It is necessary to add, however, that newly introduced or modified components should not attenuate the useful light flux if it propagates together with harmful light flux. In optics, these contradictive requirements are resolved through application of gradient amplitude correctors whose transmittance varies from the center to the periphery region as well as using by absorptive, band-pass and polarization filters [30].

For instance, in observing the faint astronomical objects nearby much brighter sources, apodization filters with radially varying optical density are used to suppress the side lobe component in the aerial image of the bright source [31].

In incandescent lamps, multilayer interference coatings called cold and hot mirrors are applied to protect illuminated objects from unwanted heat. The cold mirror reflects the visible light and let infrared radiation pass through [32]. On the contrary, the hot mirror reflects infrared radiation back toward the energy source while transmitting the visible light to the target [33].

In halogen light sources, fused silica is doped with titanium dioxide and cerium oxide to block ultraviolet radiation emitted by a high-temperature lamp filament [34].

In mentioned paper [30] devoted to optical contradictions in TRIZ, a problem on the illuminated personal hygiene mirror has been analyzed. The point at issue is how to block the highlight reflected off the skin surface, in order to see his or her skin integument in detail. This case study could be considered as the task on Su-Field destruction. In fact, the interaction of light emitted by illuminators on a mirror frame (field  $F_1$ ) with skin (substance  $S_1$ ) results two reflected waves (see Fig. 9, left-hand side):

1. Diffuse reflected wave related to light scattering in epidermis. This is a useful signal, which makes it possible to see color variations, pigmentation, hair follicles, blood vessels, and other details in deeper skin layers.
2. Specular reflected wave related to light reflection on the air-skin boundary. In our example it is unwanted signal, since glossy reflection carries mostly information about the contour of the skin surface.

Unwanted signal is eliminated due to field structuring (inventive standard 2.2.5). As described by Mullani [35], the skin surface is illuminated by linear-polarized light (field  $F_1^\#$  on the right-hand side of Fig. 9). In this case, the polarizer in front of the mirror (substance  $S_2$ ) blocks specular re-

flected radiation from the air-skin boundary<sup>1</sup>. But what action on the light field of the useful signal ensures its passage through the same polarizer? This effect is depolarization of a light wave due to multiple scattering on collagen fibers in deeper skin layers [36]. It can be seen that only resources of the analyzed object itself are used for this purpose. In other words, the light field of the useful signal is undergone to the self-action.

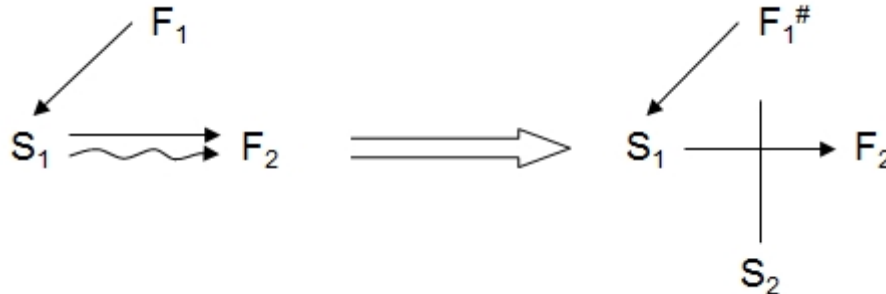


Fig. 9. Su-Field model for the personal hygiene mirror with a built-in light source.  $F_1$  – unpolarized wave from the light source,  $S_1$  – skin surface,  $F_2$  – light wave reflected from the skin surface,  $F_1^\#$  – linear-polarized light,  $S_2$  – polarizer in front of the mirror

The light self-action effect is also used in so-called nonlinear optical self-limiters [37, 38]. Under certain conditions, such devices strongly attenuate intense, potentially dangerous radiation while exhibiting transmittance for low-intensity light beams. Due to lack of power consumption, simplicity, reliability and operation speed, optical self-limiters have widely applied for defense of human eyes and delicate optical instruments from high-intensity laser radiation, for protection of highly sensitive optical sensors against bright light illumination.

Using Su-Field analysis, let us describe the problem of forming narrow-directed radiation in a solid-state laser. Major components of the laser system are an active medium and optical resonator (see Fig. 10a adopted from [39]). The active medium (substance  $S_1$ ) coherently amplifies light radiation (field  $F_1$ ) while the resonator (mirrors of that are denoted as substance  $S_2$ ) transforms the optical amplifier into an oscillator due to light wave travels forth and back through the laser medium (Fig. 10b).

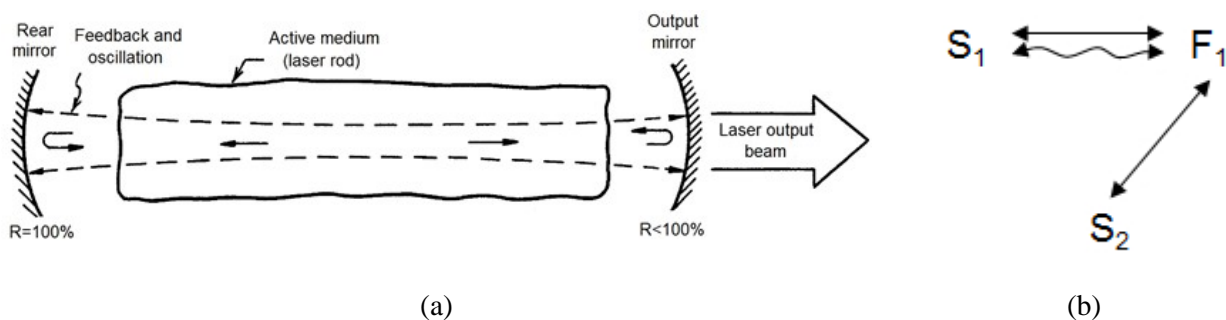


Fig. 10. (a) Major components of the laser system [39] and (b) Su-Field model of solid-state laser with induced optical inhomogeneities in the active medium.  $S_1$  – active medium (laser rod),  $S_2$  – mirrors of the resonator,  $F_1$  – light wave travelled forth and back through the laser medium

It is known that one of the reasons for increasing the angular divergence of radiation of solid-state lasers are fluctuations of the refractive index of the active medium that inevitably occur in the pro-

<sup>1</sup> In order for specular reflected wave of unwanted signal to be blocked, the polarizer  $S_2$  in front of the mirror and a polarization filter providing linear polarization of the incident light wave  $F_1^\#$  should be in orthogonal relationship to each other.

cess of generation due to non-uniform heating the laser rod [40]. Passing through the active element with induced optical inhomogeneities light wave acquires phase distortions. In Fig. 10b, this undesirable effect is marked with a wavy line between the substance  $S_1$  and the field  $F_1$ .

How to eliminate the undesirable interaction between the substance  $S_1$  and the field  $F_1$ ? Since phase aberrations in the active element  $S_1$  are unavoidable, in order to neutralize the undesirable interaction, we should act on the field  $F_1$  formed by the resonator. A smart solution, in which control of characteristics of the field  $F_1$  is exercised due to resources of the system, has been proposed by Anan'ev [41]. Suppose that the modified rear mirror of the resonator  $S_2^*$  exactly reverses the wavefront of the incident light beam so that each light ray is reflected back exactly in the direction it came from. In optics, such a transformation is called 'optical phase conjugation' [42]. As shown in Fig. 11a), if light wave reflected off the phase-conjugate mirror travels through the same phase distorting medium in the opposite direction that all the distortions are 'undone'. That distinguishes the phase-conjugate mirror from an ordinary reflector  $S_2$ . The conventional mirror simply reflects the light beam back in the opposite direction so that phase distortions are doubled on the return trip (Fig. 11b).

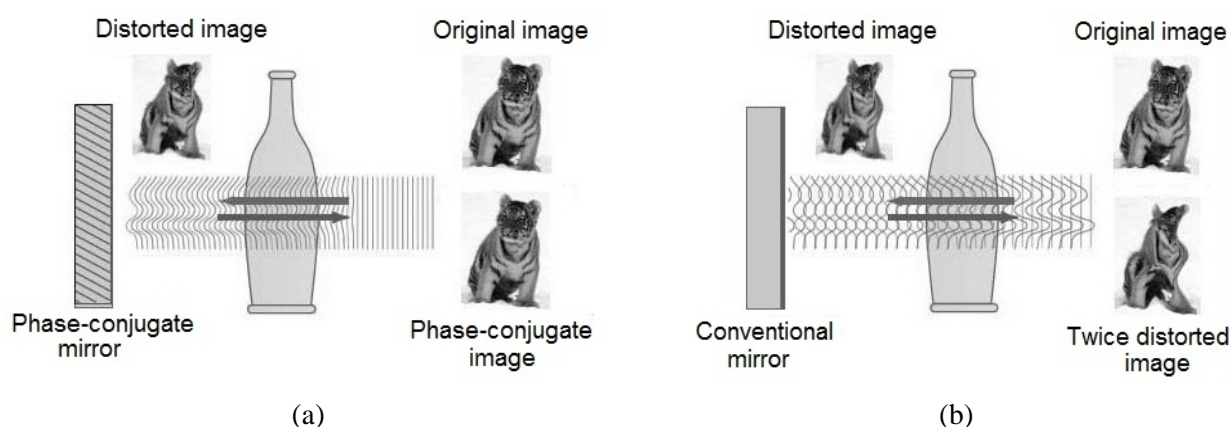


Fig. 11. The phase-conjugate mirror (a) reverses the phase front of the incident wave so that if the light trips through the phase distorting medium in the opposite direction that all the distortions are 'undone'. The conventional mirror (b) simply reflects the light beam in the opposite direction so that phase distortions are doubled on the return trip

As can be seen, the operation of optical phase conjugation represents the instrumental implementation of the inventive standard 2.3.2 "Matching the rhythms of fields". Only in that case phase distributions of fields rather than their frequencies should be matched. Thereby, standard 2.3.2 originally formulated for frequency matching can be also extended on phase characteristics of fields to sound more universally.

For optical phase conjugation, fast-acting physical processes are used: stimulated Brillouin scattering, four-wave mixing et al. [42]. For this, phase sensors, optical-mechanical correctors of wavefront and electronic control systems are not necessary. Reversed light wave results from the interaction of incident wave with one or two pump waves  $F_{EXT}$  from a high-intensity external laser source as shown in the Su-Field scheme in Fig. 12.

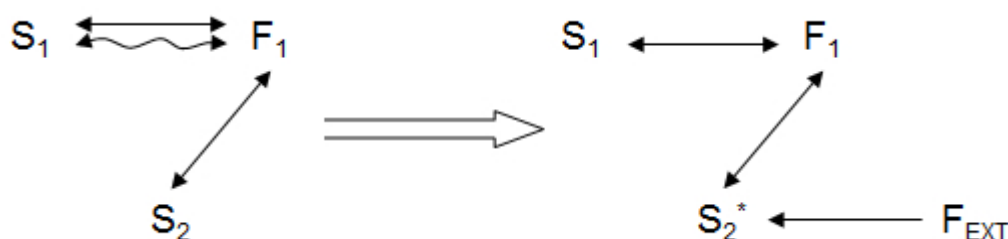


Fig. 12. Elimination of the undesirable interaction between the substance  $S_1$  and the field  $F_1$  in the Su-Field describing the trip of laser radiation through the active medium with induced optical inhomogeneities. The modified rear mirror  $S_2^*$  forms the reversed light wave by the interaction of the incident wave  $F_1$  with one or two pump waves  $F_{EXT}$  from a high-intensity external laser source

The four-wave mixing reflector may be further simplified to the passive self-organized system with a photoreactive crystal [43]. In this system, the incident wave is scattered in the crystal of barium titanate or strontium barium niobate and then internally reflected by crystal faces cut at the phase matching angle. These reflected waves then act as the pump waves for four-wave mixing. In that way, in order for the phase conjugation operation, there is no need to use an additional external laser source.

## 4. Summary

In this work, Su-Field analysis is applied for solving theoretical and practical problems in the field of optics. Case studies related to synthesis and destruction of optical Su-Fields have been considered. Su-Field models for the following optical problems have been proposed: (1) enhancement of amplitude/phase contrast for visualizing hidden or hard-to-detect objects, (2) facilitation of effective physical or chemical interaction of substances with each other using the light field with specified characteristics, (3) neutralization or attenuation of undesirable light flux that propagates through optical components together with useful light flux. We believe that materials stated in the work will be useful not only for opticians, but also for all TRIZ specialists who employ the Su-Field analysis and inventive standards for solving inventive problems.

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**Communicating Author:**

Pavel Fimin: [pavel.fimin@algo-spb.com](mailto:pavel.fimin@algo-spb.com)



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**THE INTEGRATION OF TRIZ METHODS WITH ECO-DESIGN  
AND LEAN DESIGN: A LITERATURE REVIEW AND FUTURE  
RESEARCH DIRECTIONS TO THE DEVELOPMENT OF A NEW  
MODEL**

Claudia Muiambo<sup>a</sup>, Isabel M. João<sup>a,b</sup>, Helena Navas<sup>c</sup>

<sup>a</sup>*ISEL - Instituto Superior de Engenharia de Lisboa, IPL, 1959-007, Portugal*

<sup>b</sup>*CEG-IST, Instituto Superior Técnico, Universidade de Lisboa, 1951-001, Portugal*

<sup>c</sup>*UNIDEMI, Faculty of Sciences and Technology, Universidade NOVA de Lisboa, 2829-516  
Caparica, Portugal*

## **Abstract**

This work presents a review of the literature on TRIZ methods and tools applied to eco-design and to lean design to support designers and engineers in the development of innovative sustainable product and processes. A review of existing scientific work on those subjects has the potential to guide scholars by providing examples, ideas, information and insight to the field problems and to the existing links. The specific methodology to use in this literature review starts with the formulation of the research questions to guide the review by identifying the findings of the relevant individual studies addressing the research questions specifically establishing to what extent the existing research concerning Eco-design initiatives and Lean design initiatives has progressed towards the use of TRIZ methods over the last two decades and describe directions for further research concerning the use of TRIZ in eco-design and lean design paradigms. The proposed framework including the main Eco and Lean design tools and key performance indicators usually used in Eco and Lean paradigms is presented and will be used in future work to better identify the possible gaps, issues and opportunities for further research concerning the development of a new model to integrate TRIZ with ECO-LEAN design.

Keywords: TRIZ, Eco-design, Lean Design, literature review

## **1. Introduction**

One of the main challenges in the global scenario that our societies are facing relate with the creation of equitable value for customers and stakeholders along the global value chain while fitting within the carrying capacity of supporting ecosystems and creating opportunities to meet social and equity requirements. The central driver of sustainable product design is the exploration of opportunities to innovate and design products with respect to sustainable development values. Companies across the globe are facing huge pressures from customers, regulators and other stakeholders to improve performance and reduce negative environmental and social impact of industrial processes [1, 2]. The grow of environmental concerns, tied with public pressure and stricter regulations, are deeply impacting the way companies design and launch new products across the world [3]. Everybody desires products to be sustainable, but very few are prepared to pay for products with an outspoken environmental profile [4]. According to Russo et al. [5] several eco-design methods can be found in the literature and eco-design still represents nowadays a challenge that technicians are facing since the cost of products and processes started to include the total environmental cost. TRIZ methodology for inventive problem solving has been successfully applied to

eco-design [6–9]. Russo et al. [10] highlighted that TRIZ was not developed for Eco-design yet its core principle of evolving a product to a higher level of ideality leads ultimately to more sustainable products. The authors created a methodology based on TRIZ inventive principles and a dedicated implementation of some TRIZ tools as i-Tree that is an example of an Eco-design scheme with an eco-improvement phase largely based on the TRIZ methodology.

Womack et al. [11] made the Lean concept popular through the book “The Machine That Changed the World”. The USA Environmental Protection Agency [12] defined Lean manufacturing as a business model and collection of tactical methods that emphasize eliminating non-value added activities (waste) while delivering quality products on time at least cost with greater efficiency. The aim of Lean is to develop high quality products and services at the lowest cost and minimum time by a systematic elimination of waste. Using Lean, environmental agencies have improved quality, cost effectiveness, service delivery, and responsiveness to the public without compromising environmental protection [12]. The Lean Design provides an integrated model, methods and qualitative guidelines for product design to reach the maximum value for the customer and minimize wastage [13, 14]. Dahmani et al [15] emphasized that the integration of eco-design methods with lean design can generate significant gains, allowing product design and product life cycle optimization in a Lean/green vision. The eco-design and the Lean Design have received increasing attention from academicians and practitioners that have contributed to the research and development of both fields with a lot of literature review concerning eco-design and Lean Design [16–18]. Also, a lot of work concerning the TRIZ theory of inventive problem solving has been receiving increased attention since 1980’s from the last century [19–21]. In contrast to the large number of publications concerning TRIZ or Eco-design or Lean design few have attempted to evaluate the state of the art research into the links. A review of existing scientific work on those subjects has the potential to guide scholars by providing examples, ideas, information and insight to the field problems and to the existing links.

It is not clear to what extent researchers and practitioners have engaged with the joint approach considered the benefits of TRIZ, eco-design and Lean design in the development and improvement of products and processes. This paper therefore addresses two main questions:

1. To what extent the existing research concerning Eco-design initiatives and Lean design initiatives has progressed towards the use of TRIZ methods over the last two decades.
2. What are the directions for further research concerning the use of TRIZ in eco-design and lean design paradigms. (Where TRIZ is applied? In which engineering field or knowledge context; How TRIZ is applied? Integration with other tools, what are the most popular TRIZ instruments, how they are used in the context of eco-design or Lean Design).

This Paper is organized as follows. Section 1 presents the definition and evolution of the subjects. Section 2 describes the research methodology followed in the paper. Section 3 presents a descriptive analysis of the papers identified from our literature review and reports the findings and lastly in section 4 we draw the conclusions and present the potential directions for further research.

### *1.1. Definition and evolution of TRIZ*

The theory of Inventive Problem Solving (TIPS) also known by the acronym TRIZ from the Russian Expression “Teoriya Resheniya Izobreatatelskikh Zadatch” was developed by G. Altshuller [22]. TRIZ is a combination of methods, tools, and a way of thinking [23]. TRIZ has five philosophical elements (i.e. Ideality, Functionality, Resource, Contradictions, Evolution) that are used in order to achieve absolute excellence. The five key philosophical elements are the base to develop a system of methods. It is a four-step process consisting of problem definition, problem classification, tool selection, solution generation and evaluation [22]. Gadd [24] described it as a toolkit with methods covering issues from the problem understanding to problem solving and regarded by

some as the most comprehensive and systematically organized for creative thinking methodology and invention [25].

TRIZ has spread all over the world, taught in several universities and institutes and used in several global companies to better develop their products. Also, it is being applied in combination with other improving and planning methods. Ilevbare et al. [20] present a review of TRIZ and its benefits and challenges in practice and is potentially useful for TRIZ beginners exploring the degree of usage of TRIZ tools. Chechurin [19] made a bibliometric analysis that showed the increasing attention that TRIZ produced in scientific research resulting in the growing number of indexed TRIZ related publications from few in 2000 till about 150 annually after 2011. Also, the whole approach has unquestionable results in industrial settings being hard to find a company among the Fortune 500 list without a record of using TRIZ for its innovation needs. Chechurin and Borgianni [21] made a review of the top cited publications in TRIZ where they highlight the successful implementation of TRIZ within, among the others, biomimetics and information processing.

### *1.2. Eco-design and previous literature review research on TRIZ in Eco-design applications*

Eco-design has been defined as "the activity that integrates environmental aspects into product design and development" [26] or "a systematic process that incorporates significant environmental aspects of a product as well as stakeholders requirements into product design and development" [27] or "minimizing a product's environmental impact throughout its life cycle by taking preventive measures during product development" [28]. Some other terms seem to be very similar and some definitions almost overlap. Design for environment (DfE) can be defined as "the development of products by applying environmental criteria aimed at the reduction of the environmental impacts along the stages of the product life cycle" [29] by applying environmental criteria aimed at the prevention of waste and emissions and the minimization of their environmental impact, along the material life cycle of the product" or eco-innovation defined as "any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or achieving a more efficient and responsible use of natural resources, including energy" or "the process of developing new products, processes or services which provide customer and business value but significantly decrease environmental impact". Even though a variety of terms exist, the definitions presented above are very similar and despite minor differences can be identified concerning their application, they are appropriate to use as search terms in the literature review concerning the links that might exist between TRIZ methods and their use in the context of Eco-design or some other close related topics.

Jones and Harrison [30] identified ways in which tools and methodologies from TRIZ might be used in Eco-Innovation and subsequently how TRIZ might be adapted for that specific purpose. TRIZ methodology from an environmental point of view may be used to distinguish which tools and principles are readily applicable to Eco-design from those that need to be customized.

### *1.3. Lean design and Previous literature review research on TRIZ in Lean Design Applications*

Lean design was developed from the basic idea of Lean Thinking, the idea behind this approach is to focus on value - added activities from the point of view of the end customer, hence all non-value activities should be eliminated or at least reduced during the life cycle of a product or service, such activities that do not contribute to the value of the customer are considered wasted [31]. This popular emphasis on value-added activities and on how value can be maximized resulted from the shift from waste elimination to value enhancement as exemplified in [32]. Baines et al. [33] performed a state-of-the-art review of work to improve the understanding of Lean thinking in design-related activities due to the importance of activities such as design, new product introduc-

tion (NPI), engineering, and product development (PD), areas within a company where the potential benefits of the adoption of Lean principles may be significant. An extensive list of examples shows the applicability of lean in the context of product development, such as in software design [34, 35], aerospace field [36, 37] and construction [38] just to name a few.

## 2. Research Method

This paper seeks to provide a state of the art research on TRIZ methods and tools applied to eco-design and to lean design to support designers and engineers in the development of innovative sustainable product and processes. The review of existing scientific work on those subjects is very important and has the potential to guide scholars by providing examples, ideas, information and insight to the field problems and to the existing links between the subjects. The data collected for this literature review consists of an extensive systematic analysis of the research of the last twenty years. For the search of relevant literature, we used the well-known and well-established Web of Science and search in all databases from 1997 to 2017. The selection of the last 20 years was based on previous literature review that gives evidence to the fact that TRIZ became of growing interest since 2000s specially for those who prefer their results in journals indexed by leading scientific databases [21]. Also, the number of methods and tools for environmental assessment and performance improvement rapidly increased since early 1990s due to the high number of standards, regulations and structured tools that have been voluntarily used by companies and institutes or imposed by public institutions [39]. We searched for terms like TRIZ, TIPS, eco-design, lean design, eco innovation, Design for environment, green design, green product; Life Cycle Assessment (LCA); QFD; Lean manufacturing, lean design, lean production, lean management and review. The search terms were carefully chosen to ensure that as many relevant papers as possible were included and the search was always performed combining terms like TRIZ and eco-design or TRIZ and Lean Design or TRIZ with both eco and lean design. The selection was performed by choosing papers with those words in the title, abstract or keyword fields. An initial selection was made based on the abstract to decide whether the paper should be included for further analysis. Then the dataset was cleaned up manually to eliminate those documents that were not related to the issue and were discarded.

## 3. Descriptive Analysis

A total of 100 papers was selected in the period 1997-2017. All papers were manually checked by reading the titles and abstracts to ensure that the paper fit within the study scope to omit those papers that did not address the goal of the literature review and based on that work a total of 26 journal papers and conference papers were excluded. From the remaining 75 papers a total of 58 papers is related to the integration of TRIZ methods with eco-design, 13 papers address integration of TRIZ methods with lean design related issues and only three papers addressing simultaneously the link of TRIZ with eco and lean. All papers in a certain extent referred to TRIZ in the context of eco design and related topics such as design for environment, life cycle design and so on. Also, the papers referred to TRIZ in the context of lean design and related topics such as lean thinking and lean production, were selected.

Of the 75 papers selected for the period under review, 45 papers (60%) were journal papers and 30 papers (40%) were conference papers. Fig.1(A) presents the total of 75 papers selected by journal or by conference, and Fig.1(B) presents the chronological evolution of papers from 1997-2017.

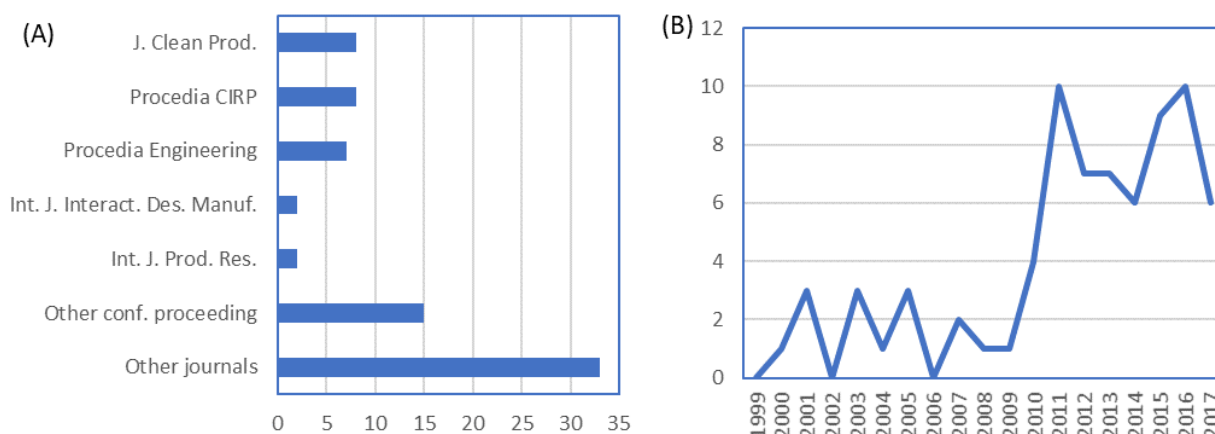


Fig. 1. Number of papers published per journal or conference (A) and chronological evolution of papers from 1997-2017 (B).

We can observe that 11% of the journal papers were published in the Journal of Cleaner Production. Approximately, 11% of conference papers were published in Procedia CIRP and 9% of conference papers were published in Procedia Engineering. A total of 15 conference papers was aggregated by other conference proceedings when its number by conference was less than two and the same procedure was performed with other journals.

### 3.1. Distribution of TRIZ plus Lean or/and eco-design publications across the period

As mentioned in section 2, we selected a period of 1997–2017 for this review and made a chronological summary of studies through the twenty year period relating to TRIZ plus Lean or/and Eco-design.

As presented in Fig1(B) there is an increasing growth trend in published journal papers and conference papers on the topics selected mainly from 2010 and later. Fig.2 presents the total number of papers and conference papers related with TRIZ+eco, TRIZ+lean and TRIZ+eco+lean.

When comparing the application of TRIZ methods and tools within eco and lean approaches, we noticed that despite the huge increase of both fields concerning the use of TRIZ there is, however a higher proportion of TRIZ tools application with eco design tools when compared with lean tools and TRIZ.

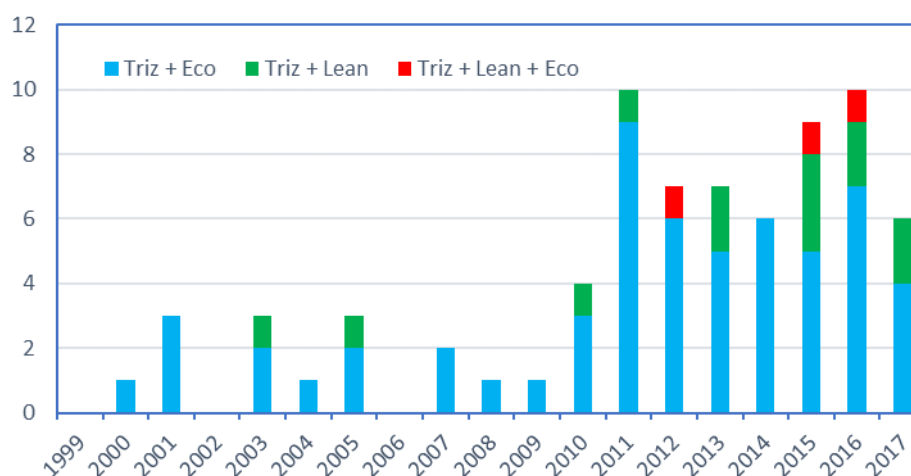


Fig. 2. Number of journal papers or conference papers by subject

Only a very small proportion (*i.e.* 4% of papers) was devoted to TRIZ+eco+lean. One of such papers used TRIZ combined with a multicriteria decision analysis method (FAHP) in the design of

an innovative product based on the concept of lean production, but not with the focus of applying TRIZ and linking eco-design and lean design approach [40]. Also, Bashkite and Karaulova [41] used a combined approach to lean fundamental thinking with green manufacturing perspective analysed with TRIZ with the main target to create the short and clear guide for the manufacturers from where to start their way to innovative, environmentally friendly and profitable manufacturing. Pacheco et al. [42] was also one of such cases combining TRIZ with lean and eco-innovation and they proposed a model to identify waste or contradictions and their elimination or reduction through the joint use of analytical tools with impact in eco-innovation based on TRIZ and Lean product service system.

### 3.2. Context of the studies

The papers were examined in terms of engineering field, knowledge context and/or industrial application. Out of the 75 papers examined 43% correspond to a variety of industrial case studies or examples from a variety of different industries where the empirical data were collected. Industrial applications include: automotive industry, chemical and bioprocess design, textile and clothing industry, ceramic industry, packaged goods, Hydropower, Generator, Cooling systems, and so on. Some publications had more than one case study or the industrial application could be widely used in multiple sectors.

### 3.3. TRIZ tools in Eco and lean design and integration with other tools

To better understand directions for further and future research concerning the use of TRIZ in eco-design and lean design paradigms the papers were evaluated in terms of tools to better understand how TRIZ was applied in Eco-design and Lean design and the integration of TRIZ tools with other tools. Table 1 presents the papers and conference papers aggregated by the most popular tools of TRIZ used in the study, the combination of TRIZ with other Eco tools, Lean tools and other tools used in the studies.

Table 1

TRIZ tools in eco and lean design and integration with other tools

	TRIZ + Eco	TRIZ + Lean
Most popular TRIZ tools		
Laws of evolution	[12, 34, 51, 43–50]	[40, 41, 69–72]
Contradiction matrix	[6, 41, 59–68, 46, 52–58]	
Inventive principles	[6, 42, 49, 50, 52–55, 59, 61, 65–71]	
Ideal final result (IFR)	[10, 41, 74, 78, 79]	
Su-field analysis	[53, 68, 80]	[72, 81]
ARIZ	[82]	[81]
Separation Principles	[52]	[83]
TRIZ associated to other tools		
Life Cycle Assessment	[10, 46, 53, 73, 78, 84, 85]	[69, 88, 89]
Case-based reasoning (CBR)	[56, 62, 86, 87]	
FMEA	[54]	
QFD	[50, 53, 57–60, 73, 90, 91]	
AHP, FAHP	[45, 57]	[40]
5S		[92]
Axiomatic Design		[49]
Theory of constraints		[83]
Lids	[93]	
Value engineering	[50]	[89]
Value stream mapping		[94]

The most frequent TRIZ tools identified in the studies were in first place the contradiction matrix and the inventive principles, followed by the laws of evolution and the Ideal Final Result (IFR) and Su-Field Analysis. Looking at TRIZ combined with other Eco design tools we identified Lyfe Cycle assessment (LCA), and Lids as the main Eco design tools. Regarding TRIZ with Lean we identified 5S and value stream mapping as the main lean tools used. Also, other type of methodologies such as QFD is one of the most used approaches, mainly in the context of eco-design and innovative design. Some other type of tools, like FMEA, are preferred by the researchers when observing the subject lean design, lean thinking or lean management. Also, the tool Case-Based Reasoning (CBR) is widely used and identified in some of the studies mainly in eco-design and innovative design context. Multicriteria Decision Making Techniques as AHP (Analytic Hierarchy Process), Fuzzy Cognitive Maps (FCMs) or Fuzzy AHP were also used and emerged as an opportunity to integrate with TRIZ in the context of eco and lean design approach.

### 3.4. Framework with Eco and Lean design tools and key performance indicators

The proposed framework including the main Eco and Lean design tools and key performance indicators usually used in Eco and Lean paradigms is presented in Fig. 3 along with the main key performance indicators (KPI's). A traditional approach to deal with contradictions between eco and lean KPI's consists on trade-offs methods by optimization, discrete event simulation or even by some rules of thumb. The TRIZ approach will have the huge benefit of dealing with the contradictions without the need of a compromise solution. The main TRIZ tools identified by the current literature review, and previously presented in table 1, can be explored further due to the advantages that have been identified in eco and lean design studies.

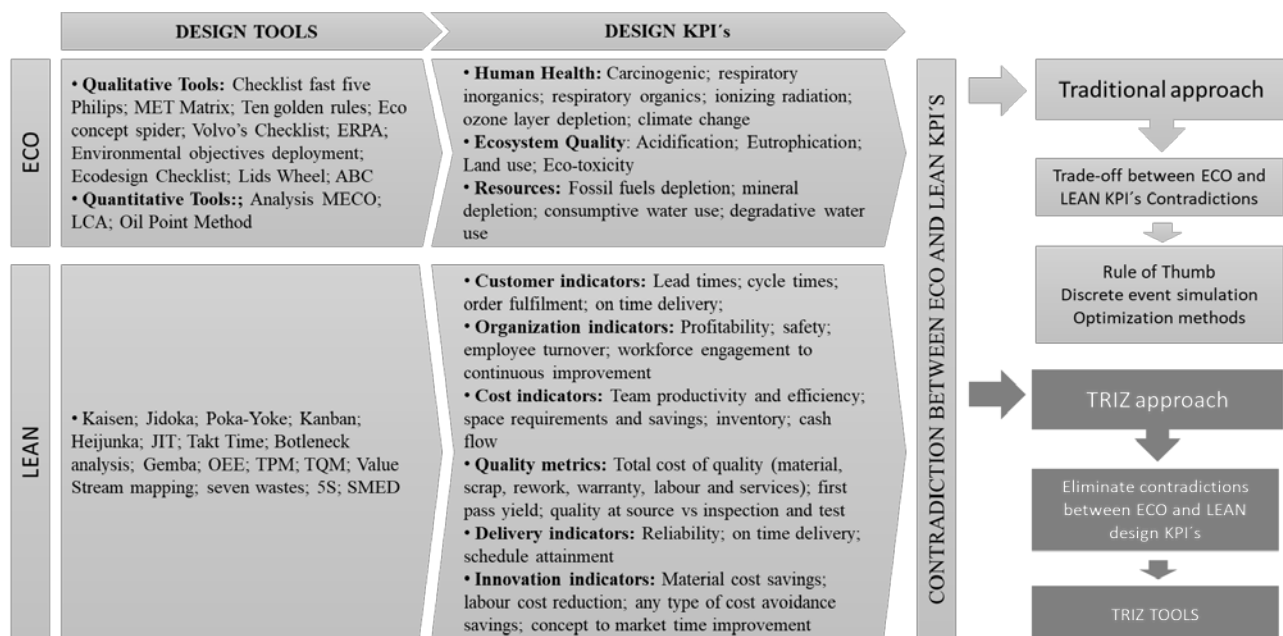


Fig. 3. Framework to combine eco and lean KPI's through TRIZ Approach

## 5. Conclusions

This paper summarizes the state of the art research on the link between the integration of TRIZ methods with Eco-design and Lean Design. The main purpose of the review was to find the relevant individual studies addressing the extent of how the existing research concerning Eco-design initiatives and Lean design initiatives has progressed towards the use of TRIZ methods over the last two decades. The main objective was to better understand directions for further research concerning the use of TRIZ in eco-design and lean design paradigms as well as the identification of

possible gaps, issues and opportunities. Based on the individual studies performed it was possible to verify that there is some work to develop in the search of models that accommodate the application of TRIZ tools with eco and lean design looking for the benefits of such models. The combination of both systems (i.e. Eco and Lean) is very challenging since most lean studies look at the environment as a valuable resource where in some eco studies the environment is seen as a limitation for product and service design and production. The current literature review was as a starting point for developing a framework including the main Eco and Lean design tools as well as the key performance indicators (KPI's) used in Eco and Lean studies. The TRIZ tools identified in the literature review will have the benefit of looking for solutions to deal with the contradictions in KPI's without the need to make trade-offs to reach the compromise solution. Further research on the topic will have the potential to guide engineers and developers to eco design and lean design with TRIZ methods and tools. The current literature review and the framework described will guide our upcoming research including the development of a new model to assist engineers and designers in the development of new or improved products or processes.

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**Communicating Author:** [claudia\\_muiambo@hotmail.com](mailto:claudia_muiambo@hotmail.com)

# **TRIZfest 2018**

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### **THE FAST DIAGRAM FOR TRIZ**

Hiltmann, Kai

*Coburg Univ. Appl. Sc., Coburg, 96450, Germany*

#### **Abstract**

C. Bytheway published his functional framework FAST in 1971. It has been widely employed in several variants in Value Engineering, but is not common in TRIZ. However, the original, logically consistent and unabbreviated form originally proposed by Bytheway can be an instructive way to model a landscape of functions outlining the system, super systems, neighbouring systems and subsystems thus depicting a system in new coordinates. In contrast to Function Analysis, possible ways of functional integration and evolution of a system can be modelled and explained; moreover, the technique constitutes a creativity tool and a strategic tool indicating disruptive innovations.

Keywords: functions, FAST, map of functions

#### **1. Introduction**

The notion of function was coined by L. Miles in 1947 [1, p. xxi], so H. Altshuller may not have known it and instead used the term of field to express the influence of one object onto another. Moreover, he used the term of ideality to describe the main function of an engineering system (ES) and to relate this function to the cost and effort required for its realization. Highest ideality thus means pure fulfilment of the main function at no cost [2, ch.2, p.83].

To the author's knowledge, the term of function was first employed in TRIZ by Gerasimov et al. in 1990<sup>1</sup> in the context of Functional Value Analysis [4] with the definition „*function is the manifestation of the properties of a material object, consisting in its action (influence or interaction) on the change in the state of other material objects*“. In 1992, Gerasimov and others introduced the function analysis, which models the interactions between the components of an engineering system (ES) and its environment – the super system – [5]. This model thus enlarges the substance-field model from the conflicting pair to the complete system and connects the notions of field and function. In 1996, Terninko and Zusman used the term in a generalized meaning of events or states of a system in their tool „Problem Formulation“ [6,7].

As will be shown, there are different concepts of functions and of their relations with different models addressing different objectives. This often causes difficulties in adequate formulation of functions.

At the task of product planning and development, analysing the functionality of products is necessary to define new products, to seek new applications, and to match market needs with the uses that products offer. A further aim in TRIZ itself is to understand the mechanisms of the so-called laws of system evolution. The functional models in use do not support this objective.

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<sup>1</sup> Souchkov mentions the year 1988 [3] but we could not identify the source

C. Bytheway developed his „Function Analysis System Technique, FAST“ in 1963 [8, sec. A2.3.2], which was originally intended to support the value analyst in correctly composing the hierarchy of functions in a functional tree [9]. To this end, he introduced a logical scheme of „how? vs. why?“ corresponding to the direction of hierarchical level and in an innovative way attributing a new meaning to the functional tree. In addition, the two questions can trigger creativity to find new ways of performing a function or finding new uses to it. The questions of how and why do not have to end at the system boundaries. If the logic is extended consistently, a functional structure is achieved that functionally connects a product with its environment and indicates chances for further evolution. This produces a functional map of needs and their fulfilment in which the borders of the product are outlined.

## 2. Function modelling

Gerasimov's definition has largely determined the definition in standard VDI 4521-1 [10] as „*influence from a system or a system component upon one or more others which changes, eliminates, or maintains a parameter of the other component or system*“. The TRIZ Function Model is a directed graph which models the components as knots and their functions, i.e. relations between the components, as edges [11]. Also standard EN 1325 for value engineering (VE) defines „*action of a product or of a component of its*“ [12], even though value analysts in practice attach more importance to formulations that inspire phantasy than describe measurable effects [13].

Other function models are [14]:

- the flow-oriented model, a block diagram with flows of energy, substance, and information as system quantities
- the relation-oriented model which describes interrelations between functions like the problem formulation,
- and the functional tree as a hierarchical system of functions.

Reports on function models have been compiled by Ponn [15], Stetter [16], and others.

The different models picture different relations, with only the two TRIZ models considering the interrelation of a system with its super system.

## 3. FAST

Bytheway's method proved successful to determine the basic (main) function of the ES. It was quickly modified by others: Ruggles introduced „*the notions of superordinate functions, essential functions, secondary functions, permanent functions, simultaneous functions, design objectives, and problem domains*“ [1, pp 11]. Snodgrass determined a fixed format, „*refers to superordinate functions as "tasks" and below them places essential functions and four supplementary functions. He designates these four supplementary functions as assuring convenience, reliability, satisfaction, and appeal, and writes that their purpose is to secure customer "acceptance" of the product.*

*The Ruggles and Snodgrass versions of FAST, with their patterned, formulaic diagrams, represent interpretations not seen in Bytheway's FAST. We can fairly say that FAST has changed course as its significance and emphasis have shifted from the application process to the diagrammed result.*“ We are reporting these changes to justify a use of FAST differing from its standard application in VE. The current formats used in VE are reproduced in Fig. 1 for standard EN 12973 (preliminary version) and in Fig. 2 for German standard VDI 2803.

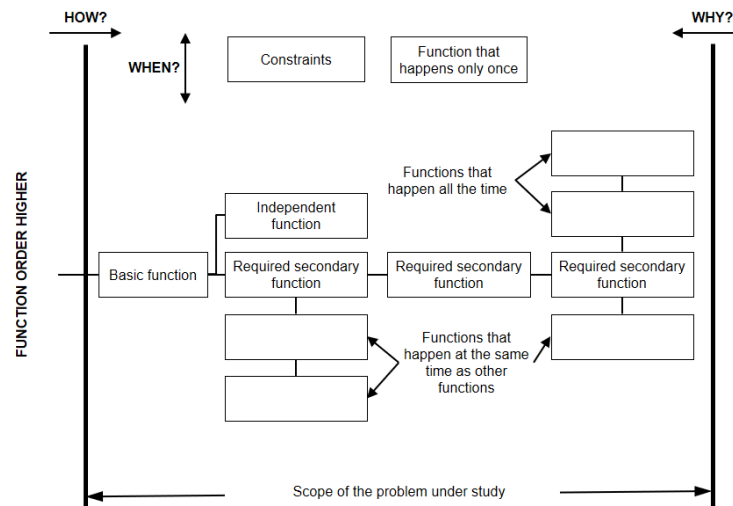


Fig. 1 FAST Diagram acc. to prEN 12973:2017. Note constraints and rarely occurring functions inserted on top and without connections

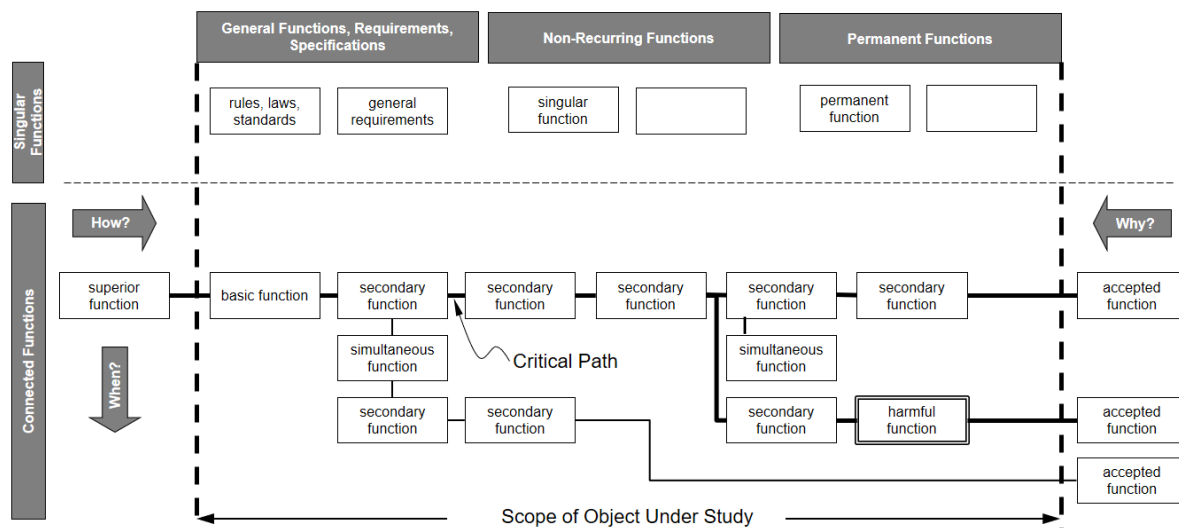


Fig. 2 FAST Diagram acc. to German standard VDI 2803: 2017. Note the “accepted functions” delivered by the super system on the right. Translation by the author; “harmful function” is called “problem domain” by Ruggles

## 4. A FAST version for TRIZ

### 4.1 Basic concept

The model we suggest for use in TRIZ is based purely on Bytheway’s original logics of “why” and “how”. To make it compatible with TRIZ conventions, we formulate functions according to the definition given above. The basic model is shown in Fig. 3: The ES performs the functions enclosed in the system boundary (replacing the Scope Lines in VE). With the “how” direction extending to the right (the coordinate system may actually be oriented arbitrarily), the first function right to the left boundary is the system’s main function (or basic function in VE). Ikonen gives a training example of a projectile hitting a soldier’s helmet and asks for the function of the helmet [17]. This may be “deflect bullet”. Asking “how is ‘deflect bullet’ performed?” one may find sev-



eral subfunctions to be required. It may be, however, that a helpful answer is “accelerate bullet [sideways]”<sup>2</sup>. In this case, subfunction 1 is a mere reformulation of the function (“deflect bullet” = “accelerate bullet”). In the second step, asking “how is ‘accelerate bullet [sideways]’ performed?”, a few subfunctions are identified, one of them being “transfer IMPULSE<sup>3</sup> [to bullet]”. Transferring impulse means simultaneously transferring a counter-impulse, in this case to the head, which constitutes a harmful simultaneous function.

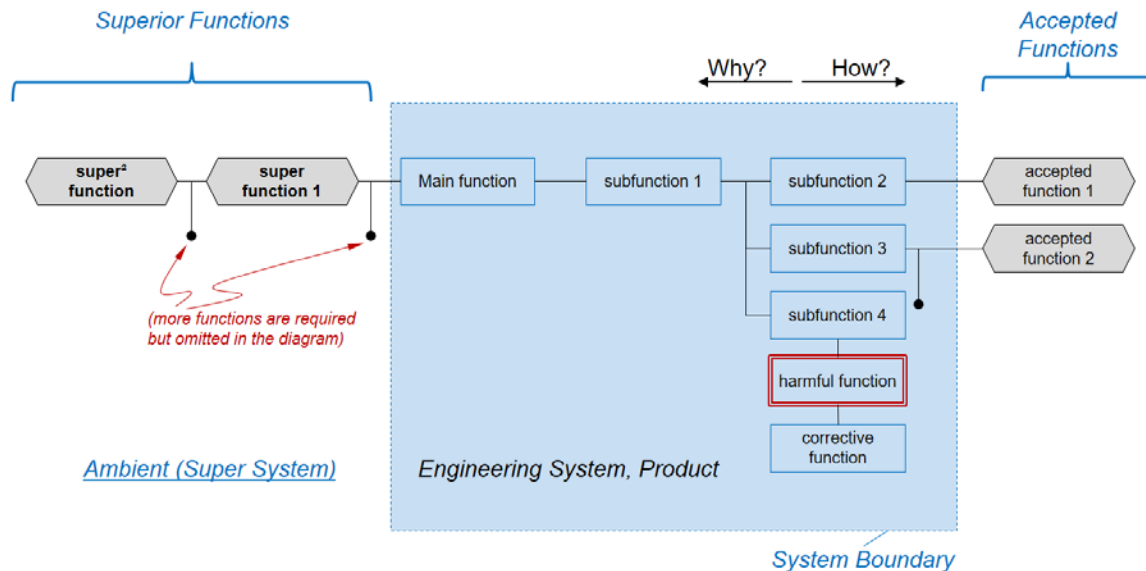


Fig. 3 Basic concept of FAST for TRIZ

Often, functions require secondary functions that are performed not by the system itself but by super system components; these are marked as “accepted functions”. Typical accepted functions are “control system”, “provide electric energy<sup>4</sup>” or “position helmet” as in the example.

On the other hand, one will ask “why is ‘deflect bullet’ performed?”. The answer is the purpose of the ES: the main function is performed to fulfil its super function, which should be formulated in a user-related way [12], i.e. “protect head”. One may continue to ask “why should ‘protect head’ be performed?”. This will lead to a secondary super function (or “super² function”) “keep body alive”. At this point, a basic boundary is reached: A human being is not an engineering system and has no purpose to meet, so no reason is required for staying alive and the functional tree has reached its starting point.

Please note in the diagram of Fig. 3 that in contrast to VE, a situation, in which only one subfunction is listed, corresponds to a mere reformulation. Sometimes, however, more subfunctions may exist but are not considered as relevant and therefore are neglected. In the example, “protect head” and “keep body alive” require more functions than just deflecting projectiles. We mark this situa-

<sup>2</sup> Since correct function formulations are difficult for beginners, we use to write the attributes of the function in [brackets].

<sup>3</sup> We use to write FIELDS in a different font

<sup>4</sup> Is “provide energy” a correct formulation? – We would say yes, because (a) electric energy has parameters voltage and amps, can influence components and be influenced, and (b) “providing” changes these parameters.

tion with an additional line ending in a bullet (as an abbreviation for "..."). In the diagram, this situation is also indicated after subfunction 3.

As a rule, every function in the ES is supposed to possess a super function, i.e. a neighbour to its "why" side. Otherwise, the respective function would be evidently useless. Therefore, we do not suggest to insert any general, singular, recurring etc. functions in this diagram as isolated boxes. The only exception to this rule are simultaneous functions, first of all harmful ones, which as a matter of course do not serve a useful purpose (they may possess harmful functions as their super functions, though, see Fig. 8). We have also marked a corrective function associated to the harmful one in Fig. 3. This seemed plausible but is experimental – we do not yet possess many experiences with simultaneous functions. At least, the fact that corrective functions lack super functions is both plausible and agrees with trimming rules for processes [17].

Please also note that the configuration of the system modelled may not be constant over time – depending on the phase in its life cycle or its momentary use, super functions, accepted functions, and even the internal functional structure may change. The diagram must therefore be redrawn for differing situations or this variability must be indicated by suitable means.

#### 4.2 Assistance in formulating functions

Identification of functions is required for various reasons. These include TRIZ Function Analysis [18], which, in turn is used for system improvement, problem solution, or cost reduction, for description and understanding the objectives of the customer as well as of an ES's structure and operation, and for analysis of a projected design task for subsequent search for partial solutions [14, 19].

When working with functions, users often encounter difficulties finding the correct formulation. Despite the definition of a function seems simple and logical, even experts get into predicaments in practice. Indeed, there are different concepts of functions as Pulm points out [20, 14]. The official VDI 4521 definition regards functions as relations between system components. Correspondingly, in his lessons Ikenovko asks for the function of an open door [17]. The answer is "none" since the open door does not interact with persons travelling through. The same reasoning may be used for a tunnel – but if tunnels had no function, there would be no reason to build them<sup>5</sup>. The concept of functions is thus closely related to the specific functional model chosen [20]. It therefore seems appropriate to translate formulations from one concept to another, which can be done easily in the FAST model. In the helmet example, "protect head" would then be a reasonable user-related formulation which is translated via secondary function into the system-related formulation "deflect bullet".

Another difficulty lies in interface functions: If the functionality of a hammer is only described as "drive nails", its usability by the worker will be omitted – a mistake that has long been made by engineers. Practitioners therefore use to formulate "hammer permits / enables / supports use" which is not correct from the standpoint of system theory since "use" is not a component and "permit" not an influence. The FAST model though can easily consider interface functions: Due to the separation in system and super system functions, there is no more need to formulate "hammer supports use" but "move / accelerate / guide / ... / hammer" in FAST is a super system function.

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<sup>5</sup> a formal argumentation in TRIZ might be to formulate a harmful function of a mountain "block vehicles" and to counterweigh it with the corrective one of the tunnel "remove mountain".

By asking “how is <function> performed?”, the structure of the system is detailed further until a satisfying level of detail is reached. Subfunctions of this level are called “elementary functions” [21 pp. 30, 22 p. 423]. It depends on the system and its user to decide which degree of refinement is elementary, as is the rule in TRIZ function analysis [18]. A machine designer will consider a motor and its function “transform electrical energy [to mechanical]” as an elementary component whereas a motor producer has to consider the components of the motor and their respective functions.

In the process that standard VDI 2221 recommends for mechanical design, function analysis among others serves to identify subordinate problems. After these have been found, their corresponding requirements ought to be conveyed to the specification sheet. We do so by first inserting comments into the diagram, Fig. 4, and then collecting the comments in the specification sheet.

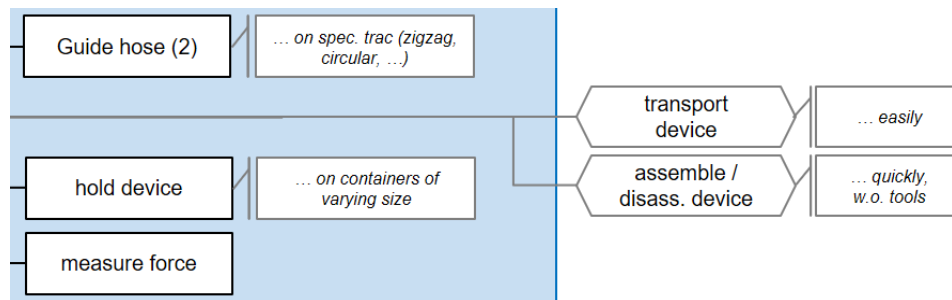


Fig. 4 Part of a FAST diagram for a fire-fighting device with comments

It may further be helpful to indicate interface parameters, especially if functions are to be performed by differing function carriers as in highly modular systems. These parameters can be entered into the model as shown in Fig. 5.

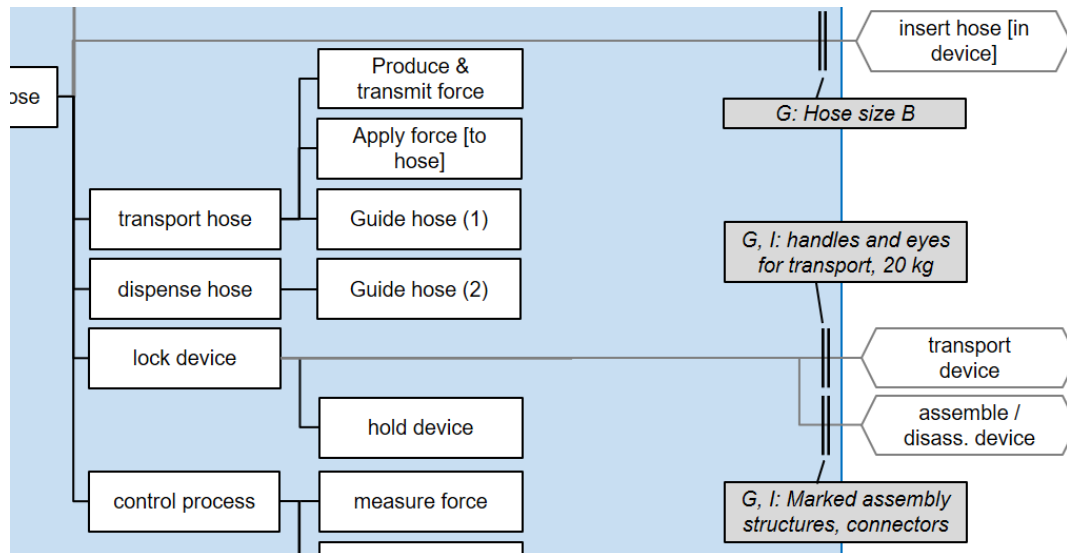


Fig. 5 Interface parameters (G geometric, I information, E energetic) entered in the model

### 4.3 Landscape of Functions / Functional Map

Typically, a system fulfils not just a single basic function, i.e. an effect on its super system, but several, including harmful ones and aesthetical functions. For instance, an electric drilling machine serves for drilling workpieces. Besides this, it can be used to produce chamfers, for threading etc., but also to stir paint and for countless other applications. We call these functions “Additional” ones, Fig. 6. Which of these basic functions is the main function is arbitrary and again depends on the user. The argument, the main function was the one the ES was built or bought for

does not hold since depending on the situation and the life cycle phase, the main function may change [23, 22 p. 423].

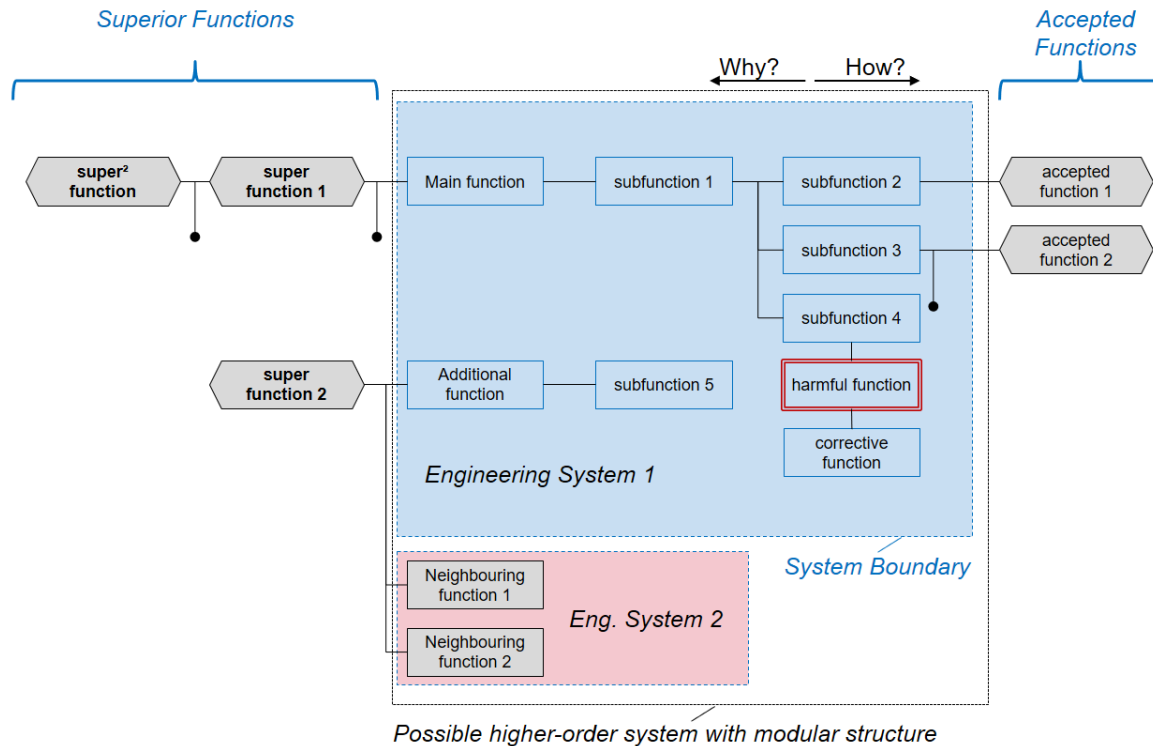


Fig. 6 A system performs several functions on its super system. On the other hand, it contributes only partially to super functions

A question that comes up when searching for additional functions is “which exactly are the functions, also unknown ones, a system can perform?” One tool to identify possible additional functions is Anticipatory Failure Determination [24, 25], another Reverse Function-Oriented Search [26] but more work is needed on this subject.

An ES always serves a superior function<sup>6</sup>; since this is a user-related function, usually a use aspect and an aesthetic aspect must be distinguished [12]. Each ES therefore uses to serve at least two superior functions but the ES is not sufficient in fulfilling these. If it was, the ES’s basic function would be just a reformulation of the superior function. For instance, a hammer serves to impact on an object and the user needs this action to drive a nail into a wall. Obviously, two more ES’s are required: The nail and the wall (and the worker). All these three (four) systems together with their respective functions can fulfil the user’s desired function which requires mutual matching.

Functions that are fulfilled externally from the ES and support the ES in serving a common superior function we call “Neighbouring Functions”. Neighbouring functions may be performed by one or more systems in the neighbourhood of the system, i.e. in its super system. The concept of neighbouring functions is important for matching their parameters, in order to increase the functionality of the ES (neighbouring functions are prone for integration into the ES), and to organize ES’s into systems of ES. This latter point is required when a product portfolio shall be defined or when an ES is to be organized into modules.

<sup>6</sup> ... which follows from its definition „man-made assembly [...] which meets a purpose” [10]

One tool of “classical” (Altshuller’s) TRIZ is the system operator. The system operator compares a system at different times and may be used to estimate the future evolution of the system. In addition, several levels in system hierarchy are considered: The system itself, its subsystems, and its super system(s). We suppose that the diagram drawn for different situations may help clarify the interrelation of ES and super systems. However, more experience is needed on this subject.

#### *4.4 Increasing Product Functionality, Updating the Product Portfolio*

One way to increase the value of an ES is to increase its functionality as is recommended especially in the first phases of the S curve [27 p. 168, 17, 28]. V. Prushinskiy recommends to merge (hybridize) the ES with an alternative one that performs the same main function [29]. We would enlarge the field of search to systems contributing to the same super function, i.e. systems that perform neighbouring functions.

With value  $V = \text{total functionality } F / \text{total cost } C$  [17], cost must be kept low in spite of rise in functionality, so synergy must be used [30] and the new products to be integrated into the portfolio must be similar to the existing ones. From the viewpoint of an engineer, similarity means technical or technological similarity. From the marketer’s viewpoint however, similarity means similarity of market. The highest similarity of market is achieved with products serving the same super function, i.e. the same need.

Likewise, new functions to be integrated into a product must use technical synergies and/or serve a known market – if possible, the same market as covered before.

The network of functions displayed by the FAST diagram supports both identification of neighbouring functions serving the same need / super function and technical synergies. We have therefore varied the functions and extended the notion of neighbouring ones, Fig. 7.

This diagram uses concepts of systems with varied parameters and competing systems that Ikonov presented with the GenTRIZ system of evolutionary laws, first of all the law of transition to the super system [17]: According to the first subtrend, the parameters of the integrating system become increasingly different from those of the Engineering System.

Let us explain the scheme given above using again the example of a hammer, Fig. 8. With “attach board” being the super function, “detach board” is the anti super function. Both are required to fulfil the secondary super function. However, the simple hammer does not serve “extract nail” which a gripper is needed for. Other functions required for attaching boards are neighbouring function “hold nail”, driving a small nail with lesser force (varied parameter, lesser hammer), and “drive screw” (competing function) together with their respective anti functions of “let nail go” and “extract screw”.

On the input side, the user will accelerate and direct the hammer at which activity he may fail, requiring a correcting function, or which he may perform in an opposite way.

In accordance with the law of evolution, the diagram now suggests extending the functionality of the hammer “horizontally” by including the functions of extracting nail, holding the nail, driving with reduced force, or driving screws. “Vertical” integration would mean to have some of the accepted functions included, e.g. accelerating and directing the tool. Vertical integration may as well extend to the “why” direction, realizing a complete system with “attaching boards” as its main function.

Search for technically similar products is done by regarding the functionality of the ES and searching for alternative uses, e.g. using Reverse Function-Oriented Search.

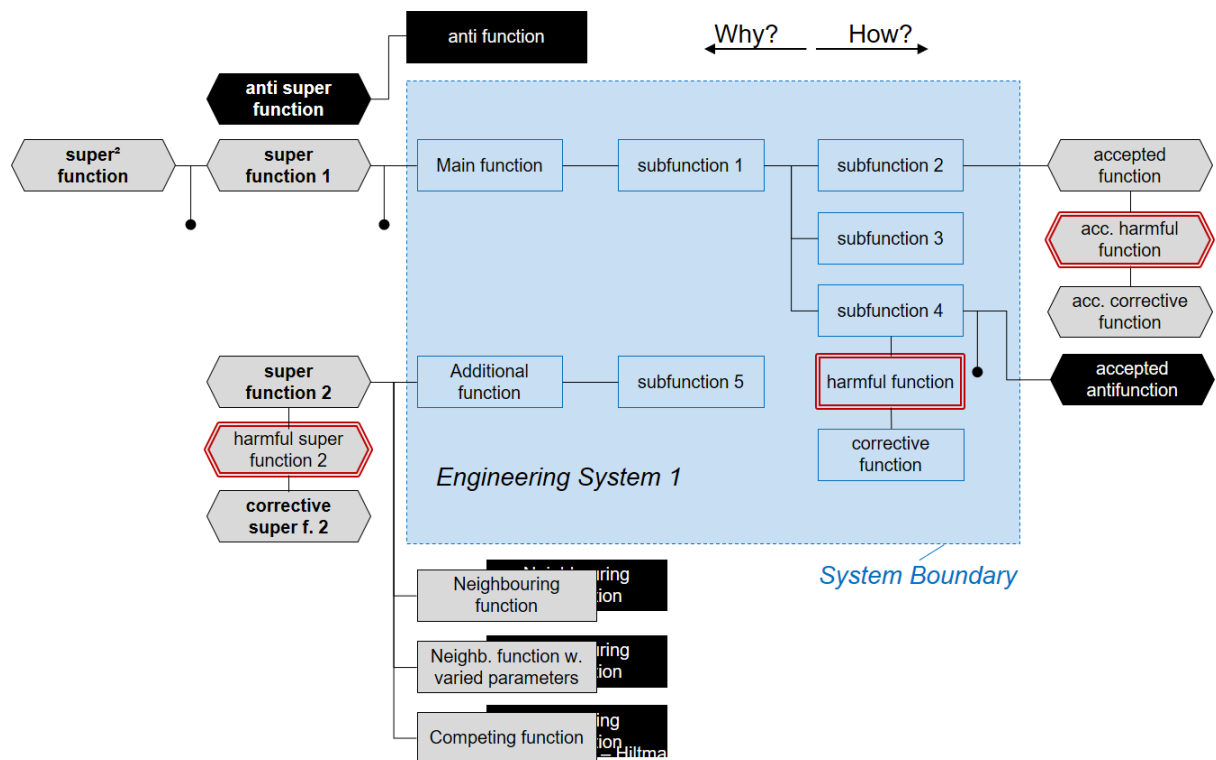


Fig. 7 FAST diagram with varied functions, see text

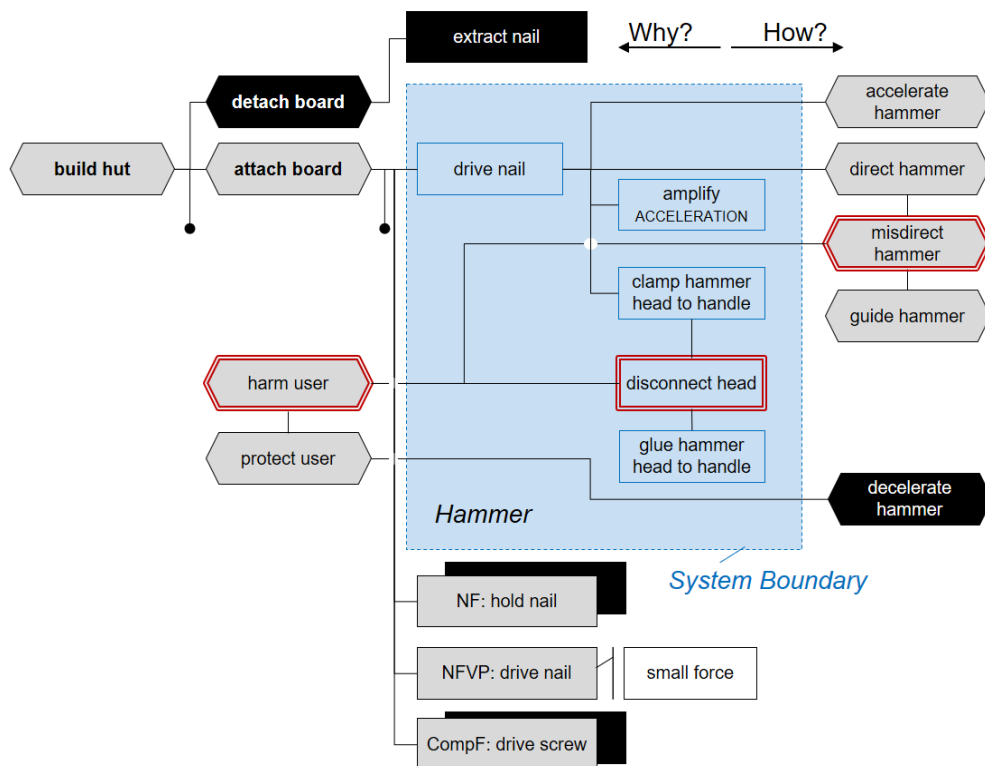


Fig. 8 Varied functions on hammer example. Example is shown for main function, but can be applied to any subfunction.

#### 4.5 *Finding Threats of Substitution*

An ES is a means to fulfil a need (its super function) and it is created in order to achieve the need using the available resources efficiently [31 p.23]. The FAST model illustrates this situation by arranging the ES between the needs on the “why” side and the resources (via accepted functions) on the “how” side. One may imagine a flow of resources streaming from “how” to “why” into the fulfilment of needs. Since there use to be competing systems, the main functions of which deliver an alternatively viable means to fulfil the need, the ES may lose the race in favour of its competitor, and vanish. Examples for this are the steam engine or the mechanical typewriter.

It must be kept in mind that the FAST model represents first of all a model of functions into which we draw the allocation with systems. Basically, the model is self-similar: What has been said above may be applied to any super or subsystem, as big or small as it may be. Therefore, in general, every subfunction has its neighbouring, competing etc. functions, which may replace it, thereby eliminating all its direct subfunctions. Likewise, a super function may vanish as it is replaced by a competing one<sup>7</sup>. The model thus permits consideration of alternative ways to fulfil a need and to monitor threats of substitution. What is still missing however, is the assessment of the risk, see discussion.

### 5. Conclusions and Discussion

We have proposed a variant of the FAST model and diagram that omits changes introduced to Bytheway’s original approach for specific needs of Value Engineering. On the other hand, we added concepts of function which result from considerations within TRIZ. The resulting scheme depicts a landscape of functions which is associated with the boundaries of engineering systems. The scheme is self-similar and applies to all hierarchical levels of functions.

The advantages of the model are seen primarily in product development: Similar to the flow-oriented model it permits to enter specifications of functions and interface parameters as well as demarcation of system levels – at least as long as they correspond with the functional hierarchy. In addition, it can present a map of needs and their fulfilment (a market-related view) and correlates this with the functionality of a product. Finally, the model supports strategic decisions by indicating functionality to be included or be trimmed out.

The aspects of trimming the model and of illustrating certain laws or trends of system evolution were not treated in this paper due to size limitations and will be presented later.

What we mentioned are changing conditions in the life cycle of a system. Souchkov pointed out that due to changes in the super system – super functions vanishing or resources running dry – systems may face becoming obsolete [32]. Evidently, a time-dependent format of the model would be desirable.

The FAST model as described here displays functions, however for strategic system planning, ideality or value is a needed information to assess future development. A task to be solved in the future therefore is how to integrate the aspect of cost. A vague idea may be to compare the flow of resources through the system with an electrical circuit or “potential problem” with cost being represented by the respective function “resistances”.

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<sup>7</sup> it is an open question if the “final” super function can vanish or not. Since it constitutes a basic human need, it is expected to last as long as mankind.

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## TRIZfest 2018

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### TRIZ APPROACH TO INTERNET OF THINGS

Simon Litvin<sup>a</sup>, Andrey Prokofiev<sup>b</sup>

<sup>a</sup>GEN TRIZ, 02465, Newton, MA, USA

<sup>b</sup>Algorithm, 190013, Saint-Petersburg, Russia

#### Abstract

Innovative products, technologies and services are the currency for economic growth. At the same time, IT hardware and software products have enabled the digital economy, including the Internet of Things. Unfortunately, there are no obvious links between the Internet of Things and incumbent product, technology and service offerings. Our hypothesis is that the role of such a link could be played by functions.

TRIZ defines a function as an action of one material object to change or maintain the parameters of another material object. All products, technologies and services exist to perform functions, and functions are the means of value creation. Main Parameters of Value (MPV) are the targets of innovation that fuel growth (e.g. strength, speed, safety, accuracy, etc.). Functions are the physical actions that drive MPV performance (e.g. to hold, to move, to damage, etc.). The collective functions of Information Technologies (IT) hardware and software products have enabled the Internet of Things (IoT) – whose primary function is “to inform”.

IoT is based on digital enabling technologies that allow to perform functions on information – to detect, to translate, to transfer, to store, to analyze, etc.

New value is created when the function “to inform” enables a step change in performance of an existing MPV of some product, technology or service, or enables a new, latent MPV. Application of the Internet of Things allows to create new Smart, Connected products, technologies and services. Such TRIZ tools as Function Analysis and Main Parameters of Value Discovery create an adapter between the world of material objects (products, technologies and services) and the world of Information Technologies.

The paper is furnished with several practical case studies

**Keywords:** *Internet of Things (IoT), Function, Main Parameter of Value (MPV), Digital enabling technologies*

#### 1. Introduction

Internet of things (IoT) from the standpoint of pure technology is a network of networks that consist of uniquely identifiable objects capable of interacting with each other through IP connection and without human intervention [1-3]. An individual IoT module comprises a sensor built in an object (thing), which reacts upon certain external stimulus or trigger. After that, either the sensor transmits information to a processing unit, which may inform the user about the

trigger event through some sort of communication interface, or alternatively it may automatically start an actuation mechanism, which then would do certain actions upon the object with the actuated sensor. It is important to note though that IoT is not just a set of sensors helping humans to set off actuators. Opportunity to transmit and process immense amount of data is a feature, which makes IoT so appealing and universally applicable across all industries and areas of human life in general. Number of scientific publications on related technologies have been exponentially grown for the last 10 years (Fig1.). Intellectual property documents (patents and applications show even more pronounced growth, reflecting tremendous level of innovation activity in related technology domains.

Data gathering and analysis has been existing for a long time. Industrial internet is radically different from the WWW by the fact that sensors are combined in a united control network, which include analytical and/or control system. Inside this network, there is a constant data exchange and automatically some control decisions are made. Thus, there are elementary manifestations of artificial intelligence. [4-5]

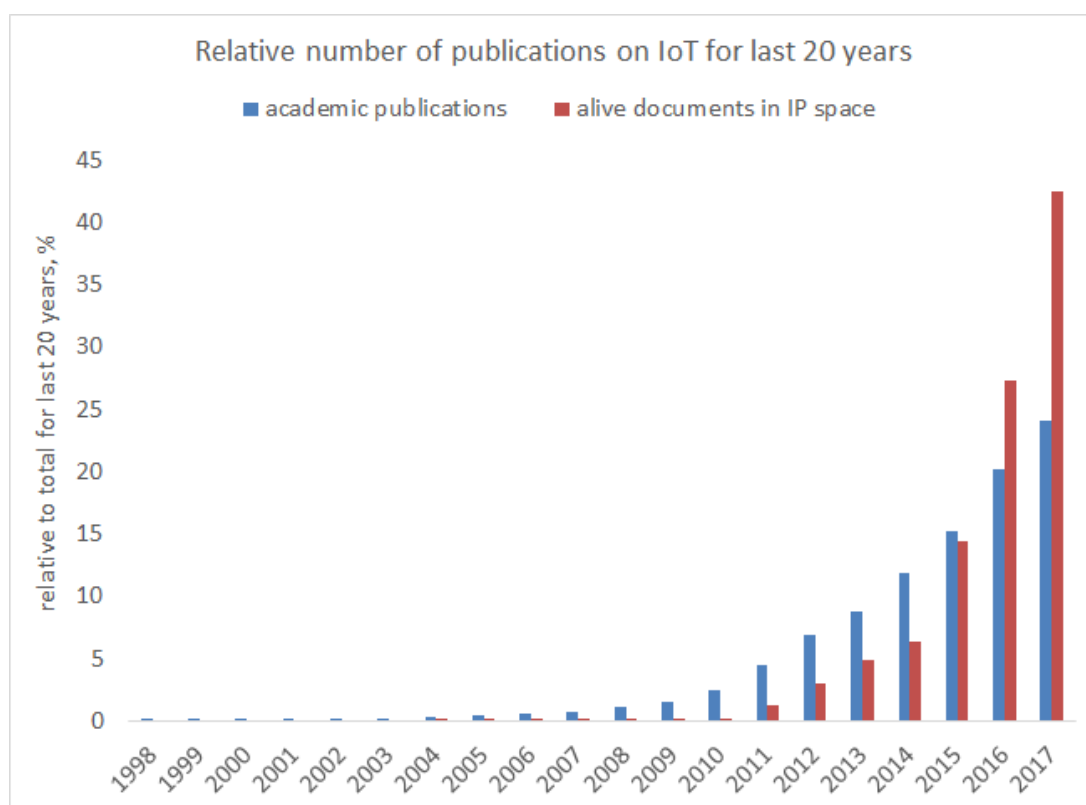


Fig.1 Number of documents (relative to the corresponding total number of publications) published over the last 20 years. Academic articles retrieved from [6]; IP documents include applications and patents and are obtained from [7]

By today, it is already true that there are more things connected to the internet than there are humans [8]. Smart home, smart transport and smart cities leverage the benefits of connected things and big data processing capabilities [9]. Medical devices and services tremendously benefit from IoT concept. So for example, wearable sensors day and night monitor vital signs of patients: pulse, temperature, blood pressure, glucose and oxygen in blood. Nowadays, there are applications, which analyze this kind of data to establish an accurate diagnosis and predict an outcome of the medical treatment [10-11].

Despite the fact that IoT is a concept that will grow and eventually penetrate most areas of human life, it has its limitations. One significant challenge is standardization of data transmission protocols is owed to the great variety of objects that can be connected into the network as well as diversity of their functions and controlled parameters [12]. Security and data safety is also a concern [13].

Clearly, IoT is a mainstream innovation trend and it is utterly important to utilize its advantages to the full capacity for emerging applications as well as developed technologies and manufacturing processes. GEN TRIZ is a company that has its core expertise in innovation services based on classical TRIZ tools developed in response to modern challenges faced by R&Ds of global industry leaders. One particular tool, which might provide solid connection between digital technologies and their applications across different areas, is function analysis.

## **2. Functional Approach**

Creating functional image of the system is a universal approach applicable both to engineering systems with specific technical problems and more broadly to market related connections between different stakeholders. Detail on building function models can be found in [14]. For the purpose of this paper, we will focus on a few aspects of functional approach that can be specifically advantageous for developing and improving an IoT based system. In order to develop a profound understanding of innovation challenges it is necessary to consider function models of the system at different granularity levels. It essentially means that function model is not limited by the product per se but rather can be built for the product environment, which includes interaction of major stakeholders, or it can reflect the product operation principle revealing deep connections between product components. Articulated in generalized form, functions render systematic and comprehensive reflection of opportunities for product or process improvement. A few benefits of function analysis, which will be illustrated later in the article, are:

- Finding new sources of values and potentially untapped market niches for the developed product
- Utilizing strengths of the system and identifying high priority challenges to address for extending development limits of the system
- Creating platform technologies to satisfy various market segments and needs

Simplified general function schematic of an IoT based system is depicted in Fig 2

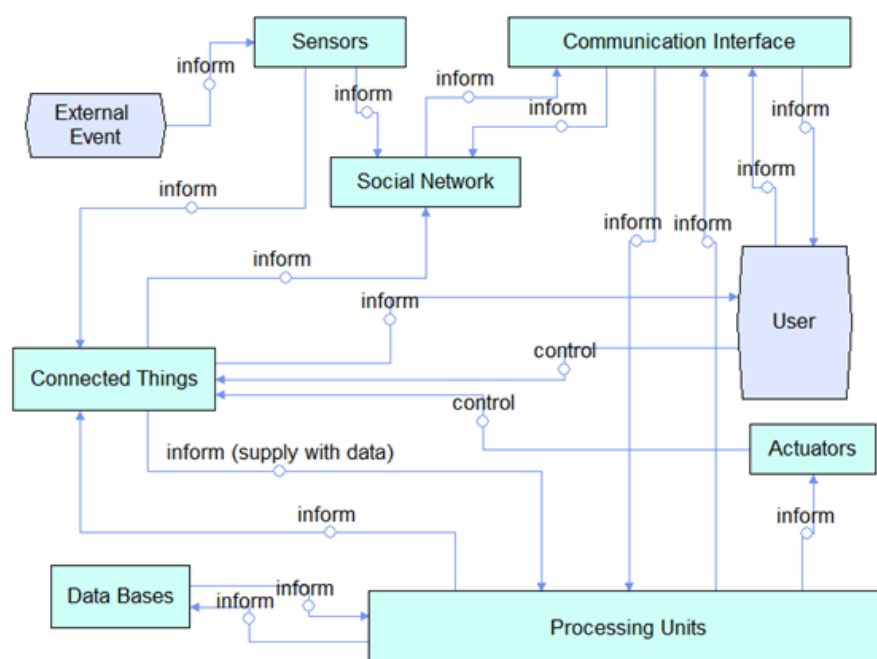


Fig. 2. General function model of an IoT system

As it can be noticed, most of the interactions between the system components are related to information transmission. There is always an external event that triggers information flows in the system. Actuator is a device, which performs actions based on the processed information. It can be used as a proxy for the user in case of simple controlling operations.

Databases can be used as a part of remote information processing architecture. They allow for accumulation of data that can be further used to take actions.

Important attribute of each function is a parameter which can be either altered or stay unchanged as a result of interaction. For a system which main function is to transmit information, example parameters would be amount of data, connection speed, and connection security. Parameters that determine success of the product on the market are called Main Parameters of Value (MPVs) [15]. They could be determined via Voice of the Customer in consumer surveys or via Voice of the Product using TRIZ tools, like Function Analysis, Cause-Effect Chains Analysis, and Trends of Engineering System Evolution. MPVs should be primary targets for innovations. It is worth noticing that for the same product different market profiles might be envisioned. Thus variable innovation target MPVs are possible for the same product. This is relevant for platform technologies [16] that could be a powerful approach for modern companies to leveraging benefits of a successful innovation

Nowadays, when many industrial companies have to operate at commodity markets it is incredibly important to find competitive advantages that would differentiate their products for the end consumers. According to extensive GEN TRIZ experience, two major approaches to producing step change improvement of a product or service (disruptive innovation) exist.

- Finding a new operation principle with greater development limit for the MPV(s). In this case they talk about a new S-curve for the product
- Identifying new sources of value by discovering new latent MPV(s)

With respect to IoT based products, a few particular steps that could constitute a high-level algorithm for identification of potentially disruptive solutions can be outlined:

- Develop function model of a product of interest.
- Analyze the system with respect to its proximity to IoT (i.e. presence of sensors, other digital components, data flows).
- In case of considered system has a direct IoT application, determine its competitive advantage (if any).
- Develop functional model of IoT system similar to what is shown in Fig.2 but with specifics for particular case
- Link function model of the product with that of IoT by answering the following set of questions:
  1. *Is there a function in the analyzed system, which provides a competitive advantage and can be incorporated into an IoT product?*
  2. *Can we improve the excessively performed functions by enhancing existing or introducing new information flows?*
  3. *Can we improve the insufficiently performed functions by enhancing existing or introducing new information flows?*
  4. *Can we eliminate or mitigate the harmful functions by enhancing existing or introducing new information flows?*
  5. *Can we introduce a new function “to inform” connecting components of the considered system? What new features or benefits would be introduced in that case?*

As a further instrument, which elaborates on the described algorithm flow analysis, can be employed. More information on the flow analysis tool is published elsewhere [17]. Developed innovation directions should then be articulated and assessed according to standard stratification procedures. In order to elaborate on the approach described above a few brief case studies have been prepared

### 3. Example Case Studies

#### 3.1 Golf Grip

One of the world's largest manufacturers of golf grips has been interesting in considering digital technologies and their integration into currently manufactured products. An idea to use smart grips is tightly connected to the IoT concept that has been viewed as a game changer in services and manufacturing. A general golf club structure is shown in Fig 3. The grip part although seems to be less sophisticated than the club head, nevertheless is very important for comfortable feeling and ultimate performance of the golf player

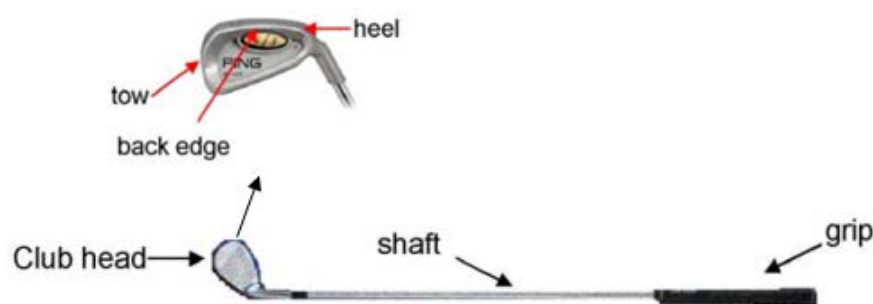


Fig.3. Description of an iron golf club [18]

Function models for different stages of golf grip lifecycle were built. A fragment of the functional architecture of the game is shown in Fig.4. A “black box” which inserted into the system functional model in this case represents the IoT diagram.

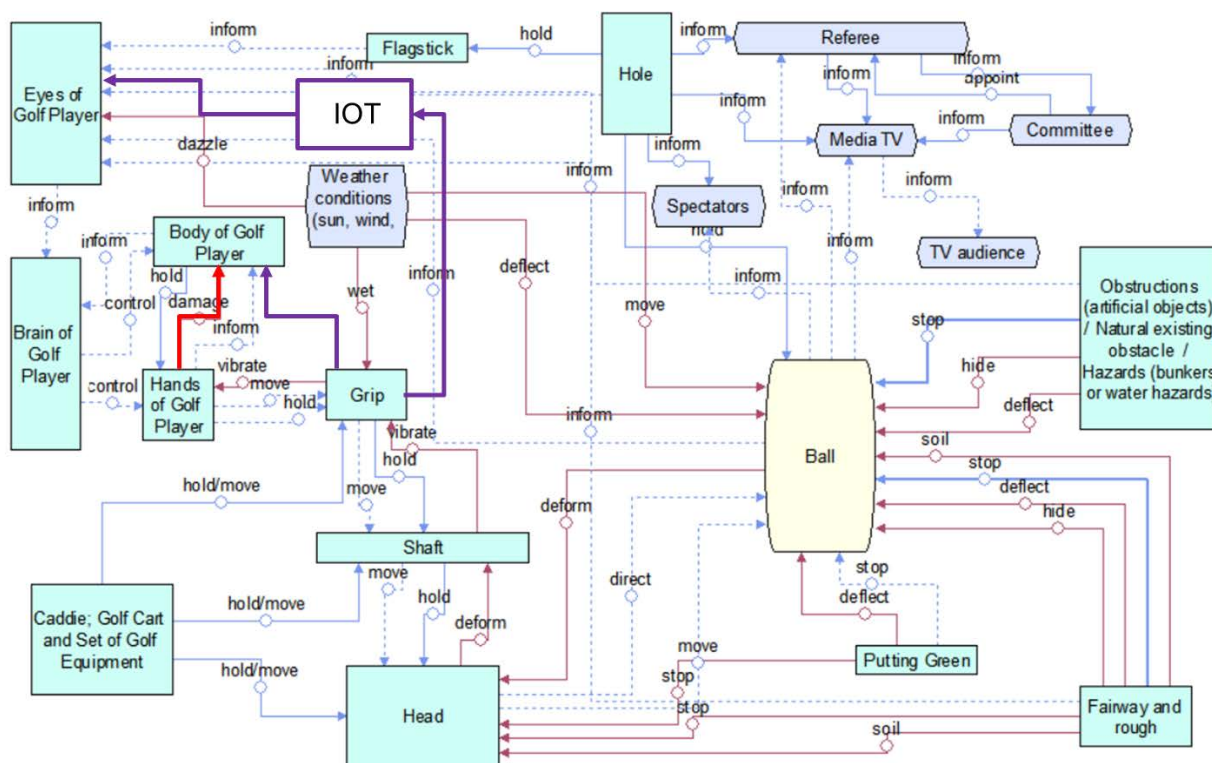


Fig.4. Partial function model for the game of golf

One could consider harmful functions and in particular the function “damage” which goes from “Hands of golf player” to “body of golf player”. It turned out that golf is rather dangerous sport. So for example, for amateur golfers the three top reasons for upper extremity damage during the golf play are “Too much play or practice (28.9%); Poor swing mechanics (21.2%); and Hit ground (24.2%)” [19]. According to above described procedure of linking IoT with a real product we can articulate a question:

***Can we eliminate or mitigate a harmful function “damage” performed by “hands of golf player” upon “body of golf player” by introducing new information flows?***

To complete the logic one could consider a detailed structure of IoT and notice its major possible components (sensors, smartphone, and wireless transmitter). With that in mind, one innovation direction appears to be evident. There are devices on the market which could track position of human body, collect statistics and draw conclusions on, for example, physical activities of the person. Similarly, we could imagine accelerometers, which monitor the golfer movements and a processor, which makes conclusions on the possibility of physical injuries because of the poor striking style. Developing further this idea a digital coach can be envisioned. Built in sensors therefore represent an appealing opportunity for the current golf grip to satisfy a latent parameter of value which could be articulated as “safe golf grip/club”

### 3.2 Smart Antenna (Airgain);



In early 2000, GEN TRIZ specialists conducted a project for a California based startup, Airgain. The goal of the project was to improve main parameters of value for a Wi-Fi antenna connecting a computer with peripheral devices (coverage, signal strength, and signal/noise ratio).

The team analyzed the system using TRIZ based tools. In Fig 5, a simplified functional schematic is reflected. Relevant harmful and insufficiently performed functions are highlighted.

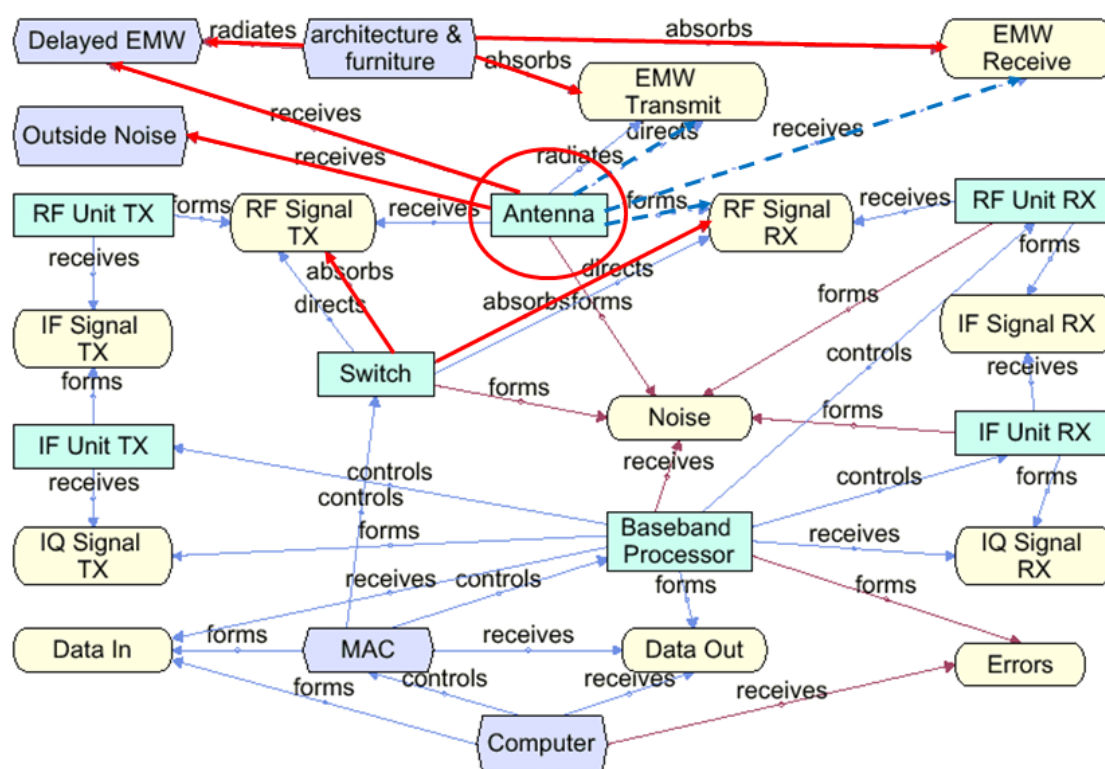


Fig.5. Partial function of a reference wireless connection unit

The team came up with a smart antenna concept, which utilizes a flexible beam forming technology that allows for mitigating RF interference and intelligent routing of high capacity data over the best available signal paths. As a result, an increased coverage, lower transmission energy and lower manufacturing cost have been achieved. A number of patents protects the proposed technology. Rephrasing the major benefit of the solution, we could say that the competitive analysis of the developed product is an “enhanced information flow”. For any IoT system, it is vitally important to have efficient information flows as it provides numerous benefits such as connecting more devices, extended operation distance, lower energy consumption and so on. Therefore, Airgain developed a range of products specifically designed for IoT applications and based on the smart beam forming technology (see Fig 6.).

In terms of business impact, Airgain Company went public in 2016 with a pretty high valuation [20] and currently continue growing.





Fig. 6. Smart home implemented with the use of smart beam forming technology provided by Airgain [20]

### 3.3 Health monitoring / Wearables (Healbe).

Back in 1999 within the framework of a project for Toshiba-tech GEN TRIZ developed a physiological model of the glucose disposal process in the human organism. After years of development, a device (wrist bracelet), which monitors calories intake and spent non-invasively was produced. In 2012, a standalone startup company named Healbe<sup>TM</sup> was founded.

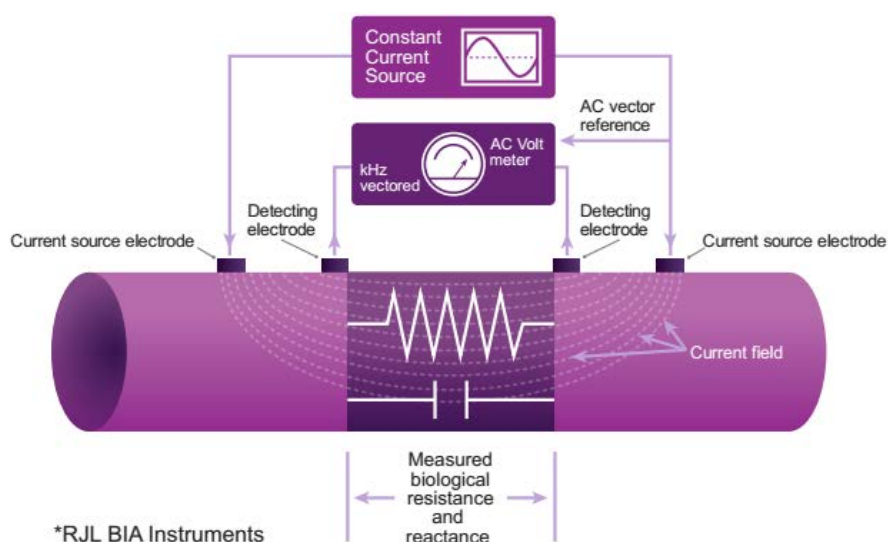


Fig. 7. Tissue bio-impedance measurement [21]

The Healbe<sup>TM</sup> model for calorie intake measurement relies on the following data:

- The level of glucose concentration in human cells. This concentration is an indicator of various physiological processes related to metabolism
- Personal data of the user (gender, height, weight, age)

Calorie intake and nutrient intake (carbohydrates, fats, water, etc.) are calculated based on these data, and on a proprietary model of the physiological metabolic processes taking place in the human organism. A key feature of the device is its ability to measure the skin full electrical impedance (see Fig.7)

Instead of marketing a standalone technology it was decided to expand the device's capability producing a platform technology based on skin impedance measurement.

***Can we introduce a new function "to inform" connecting components of the considered system? What new features or benefits would be introduced in that case?***

It was discovered that stress level and body hydration status are also connected to the skin bio-impedance. Thus, the considered feature (skin impedance measurement) can serve a base for a platform technology. Eventually a smart device with unique features was developed and successfully launched. Among standard body parameters, this device has automatic tracking of consumed calories; control of emotional state of the user; automatic tracking of water balance of the body.

## **4. Conclusions**

To summarize, this paper introduces a possible approach to developing new or improving existing products based on IoT. It is suggested that function modeling can be used to successfully integrate digital enabling technologies into real world of applications. High-level algorithm of linking an IoT system and a considered product is proposed. Authors believe that the discussed approach allows for a holistic and rigorous investigation of opportunities in the area of digital product innovations

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**Communicating Author:** [slitvin@gen-triz.com](mailto:slitvin@gen-triz.com)

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### TRIZ APPROACH TO INTERNET OF THINGS

Simon Litvin<sup>a</sup>, Andrey Prokofiev<sup>b</sup>

<sup>a</sup>GEN TRIZ, 02465, Newton, MA, USA

<sup>b</sup>Algorithm, 190013, Saint-Petersburg, Russia

#### Abstract

Innovative products, technologies and services are the currency for economic growth. At the same time, IT hardware and software products have enabled the digital economy, including the Internet of Things. Unfortunately, there are no obvious links between the Internet of Things and incumbent product, technology and service offerings. Our hypothesis is that the role of such a link could be played by functions.

TRIZ defines a function as an action of one material object to change or maintain the parameters of another material object. All products, technologies and services exist to perform functions, and functions are the means of value creation. Main Parameters of Value (MPV) are the targets of innovation that fuel growth (e.g. strength, speed, safety, accuracy, etc.). Functions are the physical actions that drive MPV performance (e.g. to hold, to move, to damage, etc.). The collective functions of Information Technologies (IT) hardware and software products have enabled the Internet of Things (IoT) – whose primary function is “to inform”.

IoT is based on digital enabling technologies that allow to perform functions on information – to detect, to translate, to transfer, to store, to analyze, etc.

New value is created when the function “to inform” enables a step change in performance of an existing MPV of some product, technology or service, or enables a new, latent MPV. Application of the Internet of Things allows to create new Smart, Connected products, technologies and services. Such TRIZ tools as Function Analysis and Main Parameters of Value Discovery create an adapter between the world of material objects (products, technologies and services) and the world of Information Technologies.

The paper is furnished with several practical case studies

**Keywords:** *Internet of Things (IoT), Function, Main Parameter of Value (MPV), Digital enabling technologies*

#### 1. Introduction

Internet of things (IoT) from the standpoint of pure technology is a network of networks that consist of uniquely identifiable objects capable of interacting with each other through IP connection and without human intervention [1-3]. An individual IoT module comprises a sensor built in an object (thing), which reacts upon certain external stimulus or trigger. After that, either the sensor transmits information to a processing unit, which may inform the user about the

trigger event through some sort of communication interface, or alternatively it may automatically start an actuation mechanism, which then would do certain actions upon the object with the actuated sensor. It is important to note though that IoT is not just a set of sensors helping humans to set off actuators. Opportunity to transmit and process immense amount of data is a feature, which makes IoT so appealing and universally applicable across all industries and areas of human life in general. Number of scientific publications on related technologies have been exponentially grown for the last 10 years (Fig1.). Intellectual property documents (patents and applications show even more pronounced growth, reflecting tremendous level of innovation activity in related technology domains.

Data gathering and analysis has been existing for a long time. Industrial internet is radically different from the WWW by the fact that sensors are combined in a united control network, which include analytical and/or control system. Inside this network, there is a constant data exchange and automatically some control decisions are made. Thus, there are elementary manifestations of artificial intelligence. [4-5]

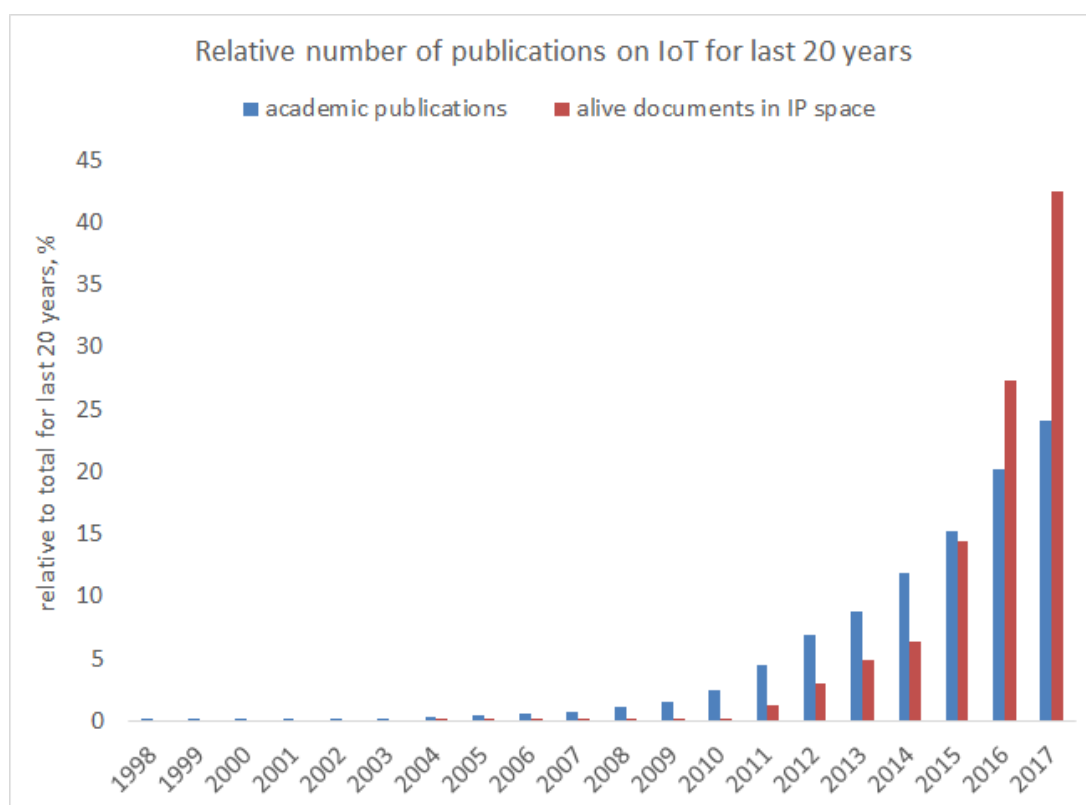


Fig.1 Number of documents (relative to the corresponding total number of publications) published over the last 20 years. Academic articles retrieved from [6]; IP documents include applications and patents and are obtained from [7]

By today, it is already true that there are more things connected to the internet than there are humans [8]. Smart home, smart transport and smart cities leverage the benefits of connected things and big data processing capabilities [9]. Medical devices and services tremendously benefit from IoT concept. So for example, wearable sensors day and night monitor vital signs of patients: pulse, temperature, blood pressure, glucose and oxygen in blood. Nowadays, there are applications, which analyze this kind of data to establish an accurate diagnosis and predict an outcome of the medical treatment [10-11].

Despite the fact that IoT is a concept that will grow and eventually penetrate most areas of human life, it has its limitations. One significant challenge is standardization of data transmission protocols is owed to the great variety of objects that can be connected into the network as well as diversity of their functions and controlled parameters [12]. Security and data safety is also a concern [13].

Clearly, IoT is a mainstream innovation trend and it is utterly important to utilize its advantages to the full capacity for emerging applications as well as developed technologies and manufacturing processes. GEN TRIZ is a company that has its core expertise in innovation services based on classical TRIZ tools developed in response to modern challenges faced by R&Ds of global industry leaders. One particular tool, which might provide solid connection between digital technologies and their applications across different areas, is function analysis.

## **2. Functional Approach**

Creating functional image of the system is a universal approach applicable both to engineering systems with specific technical problems and more broadly to market related connections between different stakeholders. Detail on building function models can be found in [14]. For the purpose of this paper, we will focus on a few aspects of functional approach that can be specifically advantageous for developing and improving an IoT based system. In order to develop a profound understanding of innovation challenges it is necessary to consider function models of the system at different granularity levels. It essentially means that function model is not limited by the product per se but rather can be built for the product environment, which includes interaction of major stakeholders, or it can reflect the product operation principle revealing deep connections between product components. Articulated in generalized form, functions render systematic and comprehensive reflection of opportunities for product or process improvement. A few benefits of function analysis, which will be illustrated later in the article, are:

- Finding new sources of values and potentially untapped market niches for the developed product
- Utilizing strengths of the system and identifying high priority challenges to address for extending development limits of the system
- Creating platform technologies to satisfy various market segments and needs

Simplified general function schematic of an IoT based system is depicted in Fig 2

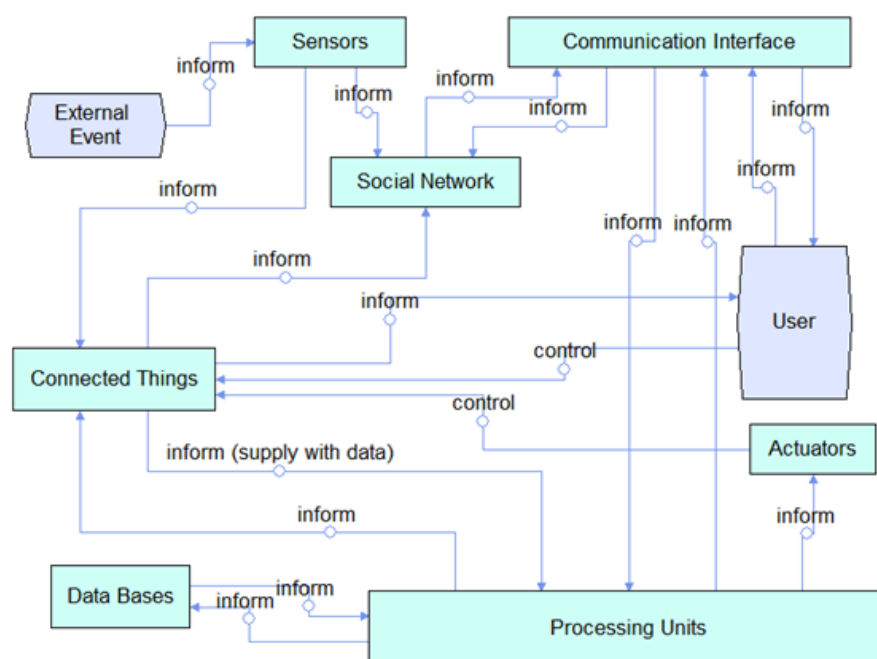


Fig. 2. General function model of an IoT system

As it can be noticed, most of the interactions between the system components are related to information transmission. There is always an external event that triggers information flows in the system. Actuator is a device, which performs actions based on the processed information. It can be used as a proxy for the user in case of simple controlling operations.

Databases can be used as a part of remote information processing architecture. They allow for accumulation of data that can be further used to take actions.

Important attribute of each function is a parameter which can be either altered or stay unchanged as a result of interaction. For a system which main function is to transmit information, example parameters would be amount of data, connection speed, and connection security. Parameters that determine success of the product on the market are called Main Parameters of Value (MPVs) [15]. They could be determined via Voice of the Customer in consumer surveys or via Voice of the Product using TRIZ tools, like Function Analysis, Cause-Effect Chains Analysis, and Trends of Engineering System Evolution. MPVs should be primary targets for innovations. It is worth noticing that for the same product different market profiles might be envisioned. Thus variable innovation target MPVs are possible for the same product. This is relevant for platform technologies [16] that could be a powerful approach for modern companies to leveraging benefits of a successful innovation

Nowadays, when many industrial companies have to operate at commodity markets it is incredibly important to find competitive advantages that would differentiate their products for the end consumers. According to extensive GEN TRIZ experience, two major approaches to producing step change improvement of a product or service (disruptive innovation) exist.

- Finding a new operation principle with greater development limit for the MPV(s). In this case they talk about a new S-curve for the product
- Identifying new sources of value by discovering new latent MPV(s)

With respect to IoT based products, a few particular steps that could constitute a high-level algorithm for identification of potentially disruptive solutions can be outlined:

- Develop function model of a product of interest.
- Analyze the system with respect to its proximity to IoT (i.e. presence of sensors, other digital components, data flows).
- In case of considered system has a direct IoT application, determine its competitive advantage (if any).
- Develop functional model of IoT system similar to what is shown in Fig.2 but with specifics for particular case
- Link function model of the product with that of IoT by answering the following set of questions:
  1. *Is there a function in the analyzed system, which provides a competitive advantage and can be incorporated into an IoT product?*
  2. *Can we improve the excessively performed functions by enhancing existing or introducing new information flows?*
  3. *Can we improve the insufficiently performed functions by enhancing existing or introducing new information flows?*
  4. *Can we eliminate or mitigate the harmful functions by enhancing existing or introducing new information flows?*
  5. *Can we introduce a new function “to inform” connecting components of the considered system? What new features or benefits would be introduced in that case?*

As a further instrument, which elaborates on the described algorithm flow analysis, can be employed. More information on the flow analysis tool is published elsewhere [17]. Developed innovation directions should then be articulated and assessed according to standard stratification procedures. In order to elaborate on the approach described above a few brief case studies have been prepared

### 3. Example Case Studies

#### 3.1 Golf Grip

One of the world's largest manufacturers of golf grips has been interesting in considering digital technologies and their integration into currently manufactured products. An idea to use smart grips is tightly connected to the IoT concept that has been viewed as a game changer in services and manufacturing. A general golf club structure is shown in Fig 3. The grip part although seems to be less sophisticated than the club head, nevertheless is very important for comfortable feeling and ultimate performance of the golf player

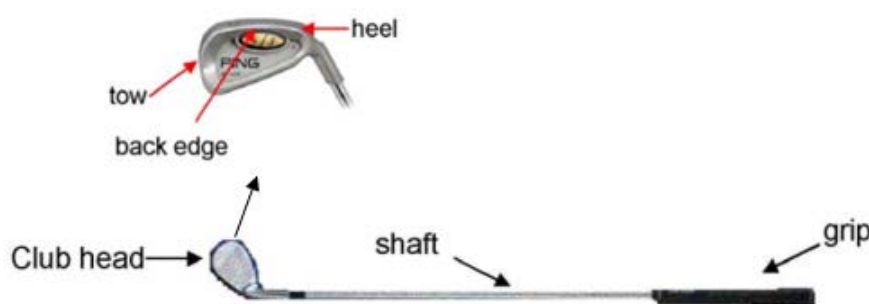




Fig.3. Description of an iron golf club [18]

Function models for different stages of golf grip lifecycle were built. A fragment of the functional architecture of the game is shown in Fig.4. A “black box” which inserted into the system functional model in this case represents the IoT diagram.

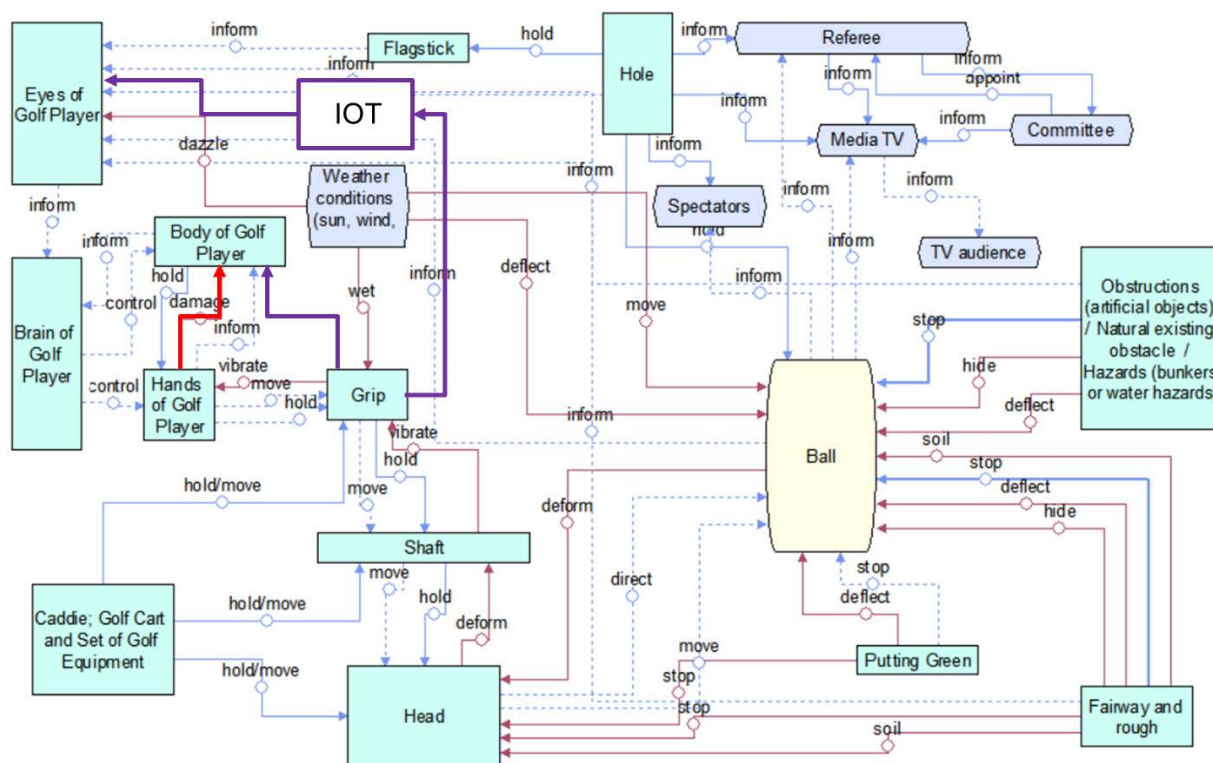


Fig.4. Partial function model for the game of golf

One could consider harmful functions and in particular the function “damage” which goes from “Hands of golf player” to “body of golf player”. It turned out that golf is rather dangerous sport. So for example, for amateur golfers the three top reasons for upper extremely damage during the golf play are “Too much play or practice (28.9%); Poor swing mechanics (21.2%); and Hit ground (24.2%)” [19]. According to above described procedure of linking IoT with a real product we can articulate a question:

*Can we eliminate or mitigate a harmful function “damage” performed by “hands of golf player” upon “body of golf player” by introducing new information flows?*

To complete the logic one could consider a detailed structure of IoT and notice its major possible components (sensors, smartphone, and wireless transmitter). With that in mind, one innovation direction appears to be evident. There are devices on the market which could track position of human body, collect statistics and draw conclusions on, for example, physical activities of the person. Similarly, we could imagine accelerometers, which monitor the golfer movements and a processor, which makes conclusions on the possibility of physical injuries because of the poor striking style. Developing further this idea a digital coach can be envisioned. Built in sensors therefore represent an appealing opportunity for the current golf grip to satisfy a latent parameter of value which could be articulated as “safe golf grip/club”

### 3.2 Smart Antenna (Airgain);

In early 2000, GEN TRIZ specialists conducted a project for a California based startup, Airgain. The goal of the project was to improve main parameters of value for a Wi-Fi antenna connecting a computer with peripheral devices (coverage, signal strength, and signal/noise ratio).

The team analyzed the system using TRIZ based tools. In Fig 5, a simplified functional schematic is reflected. Relevant harmful and insufficiently performed functions are highlighted.

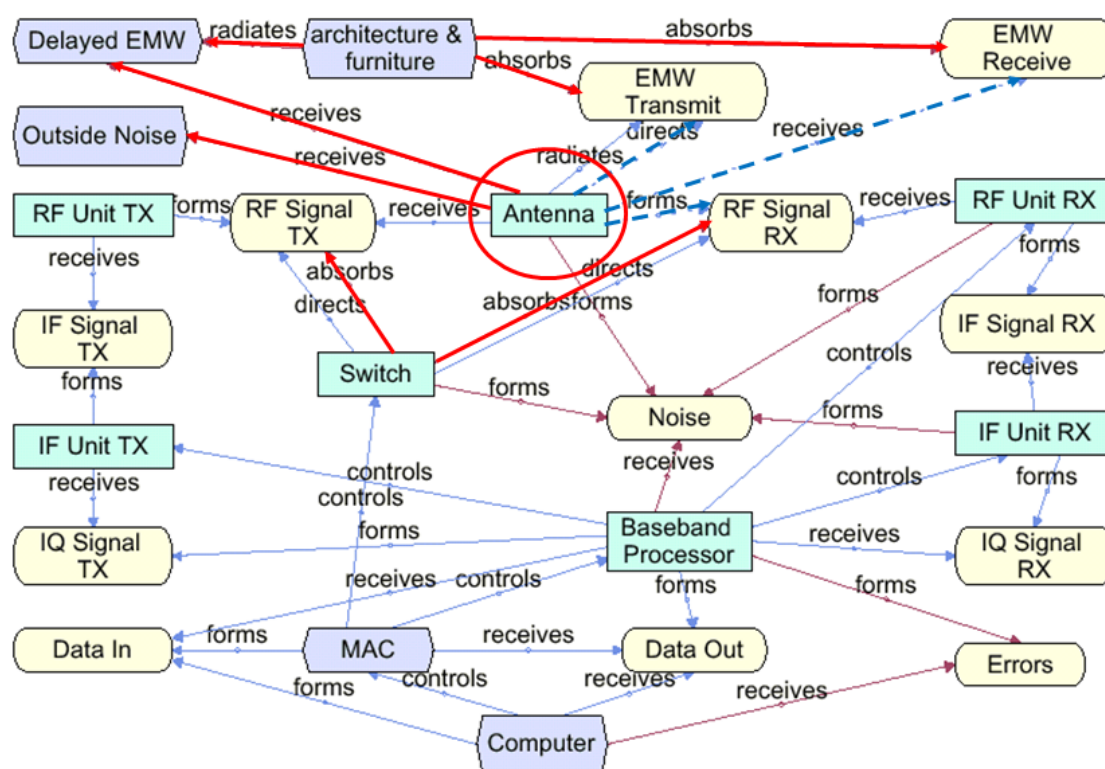


Fig.5. Partial function of a reference wireless connection unit

The team came up with a smart antenna concept, which utilizes a flexible beam forming technology that allows for mitigating RF interference and intelligent routing of high capacity data over the best available signal paths. As a result, an increased coverage, lower transmission energy and lower manufacturing cost have been achieved. A number of patents protects the proposed technology. Rephrasing the major benefit of the solution, we could say that the competitive analysis of the developed product is an “enhanced information flow”. For any IoT system, it is vitally important to have efficient information flows as it provides numerous benefits such as connecting more devices, extended operation distance, lower energy consumption and so on. Therefore, Airgain developed a range of products specifically designed for IoT applications and based on the smart beam forming technology (see Fig 6.).

In terms of business impact, Airgain Company went public in 2016 with a pretty high valuation [20] and currently continue growing.



Fig. 6. Smart home implemented with the use of smart beam forming technology provided by Airgain [20]

### 3.3 Health monitoring / Wearables (Healbe).

Back in 1999 within the framework of a project for Toshiba-tech GEN TRIZ developed a physiological model of the glucose disposal process in the human organism. After years of development, a device (wrist bracelet), which monitors calories intake and spent non-invasively was produced. In 2012, a standalone startup company named Healbe<sup>TM</sup> was founded.

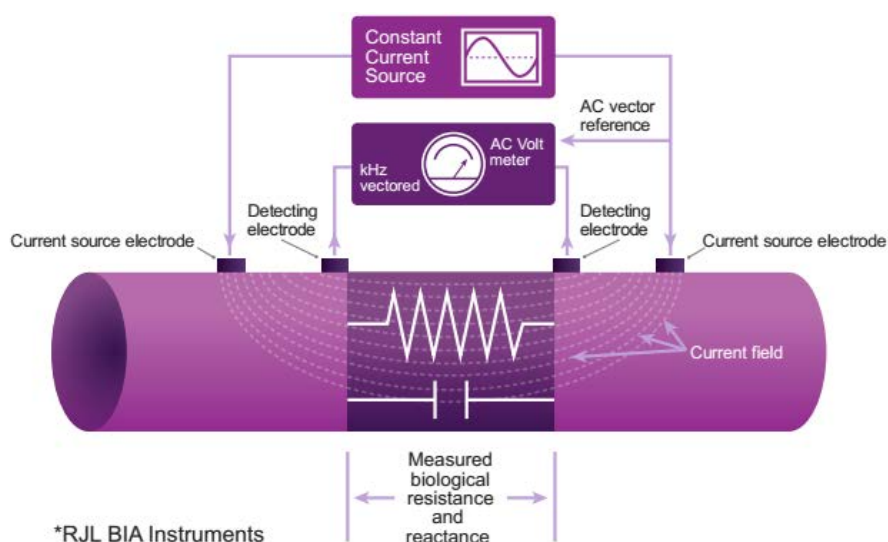


Fig. 7. Tissue bio-impedance measurement [21]

The Healbe<sup>TM</sup> model for calorie intake measurement relies on the following data:

- The level of glucose concentration in human cells. This concentration is an indicator of various physiological processes related to metabolism
- Personal data of the user (gender, height, weight, age)

Calorie intake and nutrient intake (carbohydrates, fats, water, etc.) are calculated based on these data, and on a proprietary model of the physiological metabolic processes taking place in the human organism. A key feature of the device is its ability to measure the skin full electrical impedance (see Fig.7)

Instead of marketing a standalone technology it was decided to expand the device's capability producing a platform technology based on skin impedance measurement.

***Can we introduce a new function "to inform" connecting components of the considered system? What new features or benefits would be introduced in that case?***

It was discovered that stress level and body hydration status are also connected to the skin bio-impedance. Thus, the considered feature (skin impedance measurement) can serve a base for a platform technology. Eventually a smart device with unique features was developed and successfully launched. Among standard body parameters, this device has automatic tracking of consumed calories; control of emotional state of the user; automatic tracking of water balance of the body.

## **4. Conclusions**

To summarize, this paper introduces a possible approach to developing new or improving existing products based on IoT. It is suggested that function modeling can be used to successfully integrate digital enabling technologies into real world of applications. High-level algorithm of linking an IoT system and a considered product is proposed. Authors believe that the discussed approach allows for a holistic and rigorous investigation of opportunities in the area of digital product innovations

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**Communicating Author:** [slitvin@gen-triz.com](mailto:slitvin@gen-triz.com)

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**SELECTING AND VALIDATING KEY PROBLEMS IN TRIZ  
PROJECTS**

Arthur Lok Project Director,  
*Innovation Empowerment Center, Shanghai, 200082, China*

**Abstract**

Identifying key problems is the magic moment in solving technical problems with TRIZ. Problem analysis tools, such as Function Analysis and Cause-Effect Chain Analysis, are very helpful for identifying key problems. However, what these tools provide is actually a candidate pool of key problems. In real TRIZ projects, it normally takes a lot of time to select and validate the key problems. Practitioners normally feel that they lack the “wisdom” to select the right problem to solve after performing Function Analysis and Cause-Effect Chain Analysis, so we believe it is helpful for them if we further clarify how to select and validate key problems. This paper suggested a new algorithm to select and validate key problems after performing cause-effect chain analysis. Also, it suggested that in technical contradiction and physical contradiction, we should also re-visit they key problems to solve when we generate ideas based on inventive principles and separation principles.

Keywords: Cause-Effect Chain Analysis, Key Problem, Inventive Principles, Separation Principles.

**1. Introduction**

In classical TRIZ process, there are a lot of problem solving tools, such as Engineering Contradiction, Physical Contradiction, Inventive Principles, Separation Principles, etc. At the same time, Altshuller has incorporated “problem selection” steps in ARIZ [1]. Later, in mordem TRIZ methodology, many more problem analysis tools, like Function Analysis, were developed. Problem definition is very important, just like Einstein said, “If I had an hour to solve a problem I'd spend 55 minutes thinking about the problem and 5 minutes thinking about solutions.” For many TRIZ people, problem analysis tools are even more frequently used in hands-on projects.

Root Cause Analysis (RCA) [2] is a frequently used tool in quality management and problem solving. Based on RCA, Litvon[3] developed Cause-Effect Chain Analysis (CECA), which helps to identify key disadvantages after by modeling the cause-effect logic in a tree-format. To better formulate the problems and contradictions, Souchkov[4] developed Root Conflict Analysis+ to elaborate contradiction during the process of developing the cause-effect tree.

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



When we pick the key disadvantages, normally we need to check all the disadvantages on the cause-effect chain, i.e. every dot on the tree. Then we have a long list of key disadvantages, which makes it very difficult and time-consuming trying to solve all the problems in the list.

When R&D engineers use CECA in a real project, the cause-effect chain is usually quite long. For example, in a noise reduction project, we have a pretty big 'tree' of Cause-Effect Chain Analysis, including 8 to 10 layers. In that case, the list of key disadvantages may include more than 20 items.

Normally we rely on engineers' past experiences to choose the key disadvantages. However, different people have very different understanding about the key problem in the same project team. Furthermore, for young engineers, it is very difficult for them to pick the key disadvantages. And project teams normally spend quite a long time before they really find the key problems.

In this paper, the author created a list of criteria for evaluating key problems, and then further suggested an algorithm to select key problems after performing CECA. With the algorithm, TRIZ practitioners will be able to focus on a shorter list of problems, thus more efficient in solving the problem. Furthermore, they are more confident in solving the problem, because they are more focusing on fewer problems.

## **2. Cause-Effect Chain Analysis**

### *2.1 Key Steps of CECA*

When we perform CECA, the author uses the following steps:

Step 1: Define the beginning disadvantage.

Step 2: Describe the scientific phenomenon and principles related with the beginning disadvantage, and list the possible intermediate disadvantages according to scientific phenomenon and principles.

Step 3: If it is not possible to follow a scientific phenomenon and principles, then select a logical cause-effect structure to list the intermediate disadvantages.

Step 4: Use 'And' or 'Or' to indicate the relationship between the intermediate disadvantages.

Step 5: Repeat step 2-4 to further extend the cause-effect chain, until we meet the criteria for stop.

Step 6: Select the key disadvantages.

### *2.2 Principles to follow when performing CECA*

In previous literature[5], the author suggested 3 principles to follow during the process of Cause-Effect Chain Analysis:

- Principle 1: "Cause" rather than "Purpose".
- Principle 2: Refer to physical, chemical or other scientific law.
- Principle 3: MECE (mutually exclusive and collectively exhaustive).

If we follow these steps and principles, normally we are able to come up with a very comprehensive analysis, although normally we need to do it several times before we have a satisfiable result.

### **3. The criteria for key problem.**

However, After we perform CECA, we get a list of many key disadvantages. And for each key disadvantage, we need to formulate a problem or contradiction, and use problems solving tools to generate ideas. Because of that, we need to spend a lot of time in formulating and solving the problems. Since we normally have a big tree of cause-effect chain, there are many new ideas generated. Then we could try the ideas one by one to determine which idea is the best one. Again, it is extremely time-consuming if we prototype the ideas one by one. Sometimes engineers confuse this methodology with trial-and-error. After all, they still need to try the ideas one by one.

Is it possible to find the solutions with fewer trials? In TRIZ methodology, we always seek a more systematic and efficient way to solve the problem. If we want to solve the problem with fewer trials, then we need to further pick the key problem to solve from the list of key disadvantages. So is it possible to have a structured process to pick the key problems after performing Cause-Effect Chain Analysis?

Before we answer this question, we first need to clarify what is the definition of a Key Problem. According to the past experience, the author suggested the following criteria for key problem:

- **Root-Cause.** The key problem should be a root-cause problem. For example, the wearing of a gear is a superficial problem. While the repeated vibration of the gear is closer to root-cause.
- **Small and focused.** The key problem should be a small and focused problem, instead of a big and generic problem. For example, noise is a big and generic problem, while the air flow through a nozzle producing noise is a small and focused problem.
- **Bottleneck.** The key problem should be a bottleneck problem so as that if we solve this problem, then the whole problem is solved. For example, when we drive on the road, one of the bottleneck problems is the attention span and response lead time of the driver. If the drivers don't have these physiological limits, then they could be much better at making the right decisions during driving.
- **Fresh and Insightful.** The key problem should provide new insights, which means it is fresh for the project members, and solving it will require new ideas. If it is a problem the project members has already known for quite a while, then it is normally not a key problem.
- **Within Frame.** The key problem should be a problem that is within the scope of the project, rather than a problem outside the system. For example, if we want to improve indoor air quality, one of the problem is the air quality of the environment, but this is not what we are able to control within the project scope. In contrast, the problem of gas release from furniture is a problem within frame.



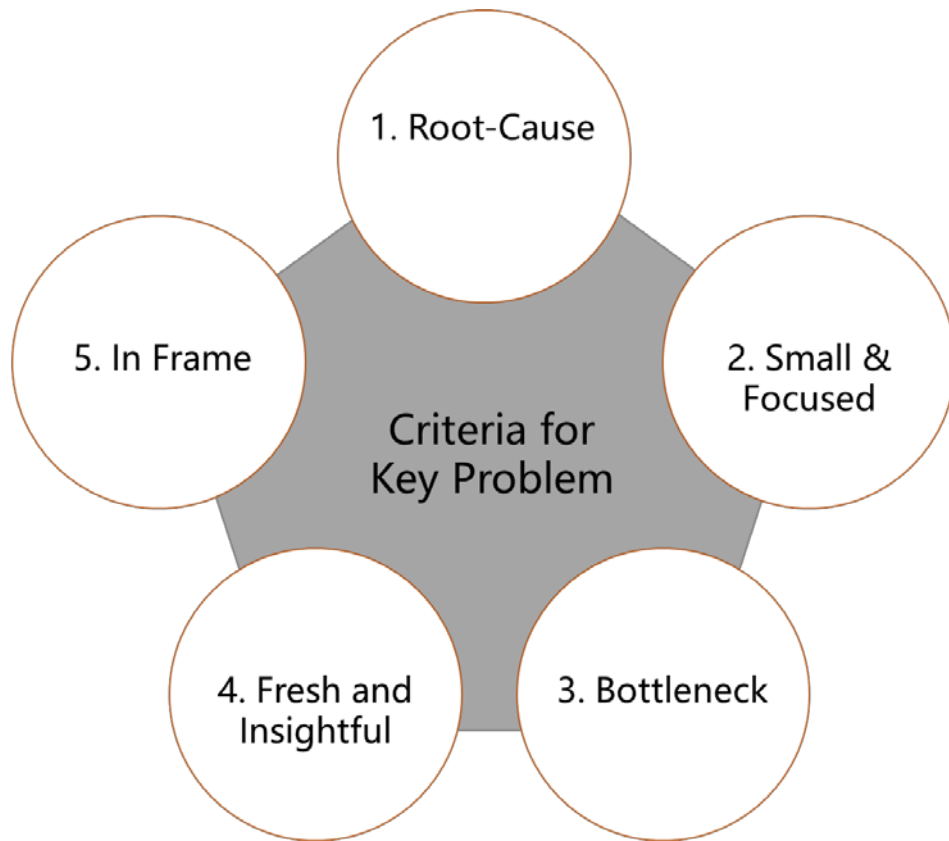


Fig. 1. Criteria for evaluating key problems

#### **4. Defining & Validating Key Problems in TRIZ Process**

How should we define the key problems? It is a tough question, and there was few literature addressing this problem. Based on the experience of hands-on projects, the author suggested an algorithm to define and validate key problems. Please see below figure of the algorithm.

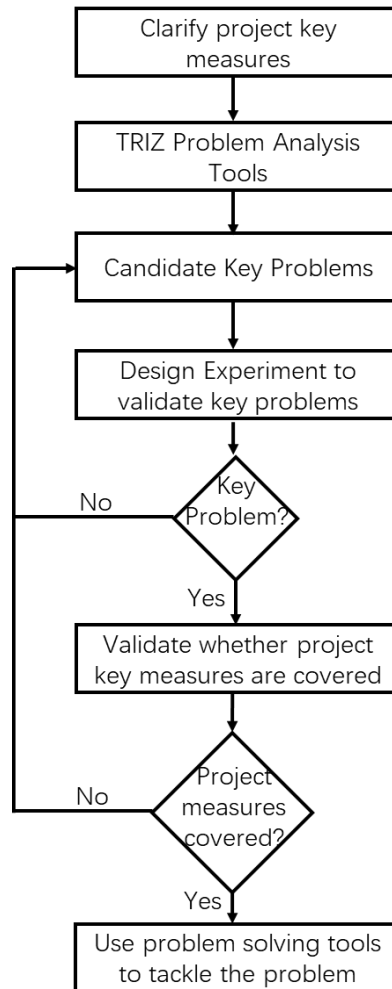


Fig. 2. Algorithm for selecting and validating key problems

#### 4.1 Clarifying key measures for the project goal.

In most cases, when we want to solve a technical problem, we already have clear measures and standards for the objective. But sometimes the key measures are not that clear. For example, in a R&D project, the objective is to design a pan that is easy to clean. Although it is a very clear problem, but there is not a clear measure. However, if we describe the objective as 'Consumers could clean the pan within 10 seconds', then we have a clear measure.

#### 4.2 Applying TRIZ problem analysis tools.

We use problem analysis tools to really understand the essence of the TRIZ problem. The problem analysis tools include Function Analysis, Cause-Effect Chain Analysis, and Trimming, etc.

#### 4.3 Candidate key problems.

After problem analysis, we create a list of candidate problems based on the results of the problem analysis.

#### 4.4 Design experiments to validate the key problems.

Before we rush into problem solving, we need to first validate the key problems. It is more efficient if we only solve the most important problems. However, it is very dangerous if we neglect some very important problems during selection. So we have to gain scientific data to support our selection. In this stage, we need to go through an iterative process. We design experiment, we obtain data, and we gain knowledge about the project, so that we have evidence to prove that we select the right key problems.

#### *4.5 Validate whether the project key measures are already satisfied if we solve the key problems.*

After we have confirmed the key problems, we need to validate whether solving these problems will lead to the fulfillment of the key measures of the whole project, which we identified in Step 4.1.

#### *4.6 Use problem-solving tools to tackle the problems.*

Now we are very confident that we have got the right key problems, and it is a very short list of problems. Then it is time to enter the problem solving stage.

### **5. Revisiting Key Problems during problem solving process.**

After we confirmed the key problem, it is very important to keep in mind that we should keep our focus on the key problem. When people generate solutions with technical contradiction, physical contradiction and inventive principles, they often forget about what is the key problem, which leads to the fact that they often come up with generic, or even irrelevant solutions.

For example, when airplane engineers design the engine, they want to have a very light engine, and one of the key problems is that the blade of the engine needs to be very strong, so they are quite heavy. In such case, normally people start to frame the problem as a technical contradiction between the weight & the strength. Then when they generate ideas based on the inventive principles, and come up with the following ideas: using carbon fiber blade; building smaller planes; using multiple smaller engines, etc. These ideas are not directly related with the key problems, actually you don't need any TRIZ tools to come up with these ideas.

So the author suggests that before we generate any ideas with inventive principles, we need to revisit the key problem. For example, when we use the inventive principles to solve the blade problem, we have to keep in mind that we want the single blade to be both strong and light. So all the ideas should be related with that. For example, creating a blade internal structure just like the bone of a bird; using arc structure to increase the strength of blade, etc.

### **6. A case study about key problem.**

Here the author would like to elaborate the algorithm with a case study from a real R&D project in which we reduce the noise of a machine by 10 decibels.

#### *6.1 Problem Description*

In a noise reduction project, we want to reduce the noise of a machine during the working process. The whole machine is designed to mix the liquid. The working process of the machine includes the blending stage and the cleaning stage. The blending stage is when the machine is performing the main function, while the cleaning stage is when the machine is getting ready for the next cycle. The machine is composed of several components: Component A, which provides the driving force;

Component B, which is the transmission system; Component C, which is a container; Component D, which is a blending component; and Component E, which is a cover.

The objective of the project was to reduce the noise of the machine by 5 dB. The initial idea to reduce the noise was to reduce the rotation rate. But reducing the rotation rate brought big problems during the working process, because we need to guarantee the efficiency of working. So engineers got stuck.

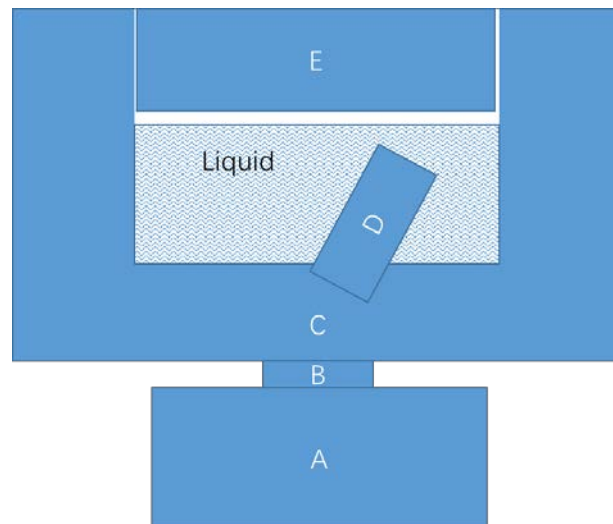


Fig. 3. the components of the machine

### 6.1 Clarifying project key measures.

In this project, the key measure was described as reducing the noise by 5 dB. To further clarify the key measures, we decided that the key measure is to reduce the peak noise by 5 dB, instead of the average noise.

### 6.2 Cause-Effect Chain Analysis.

In this project, we mainly used the Cause-Effect Chain Analysis. Below is the initial version of the analysis.

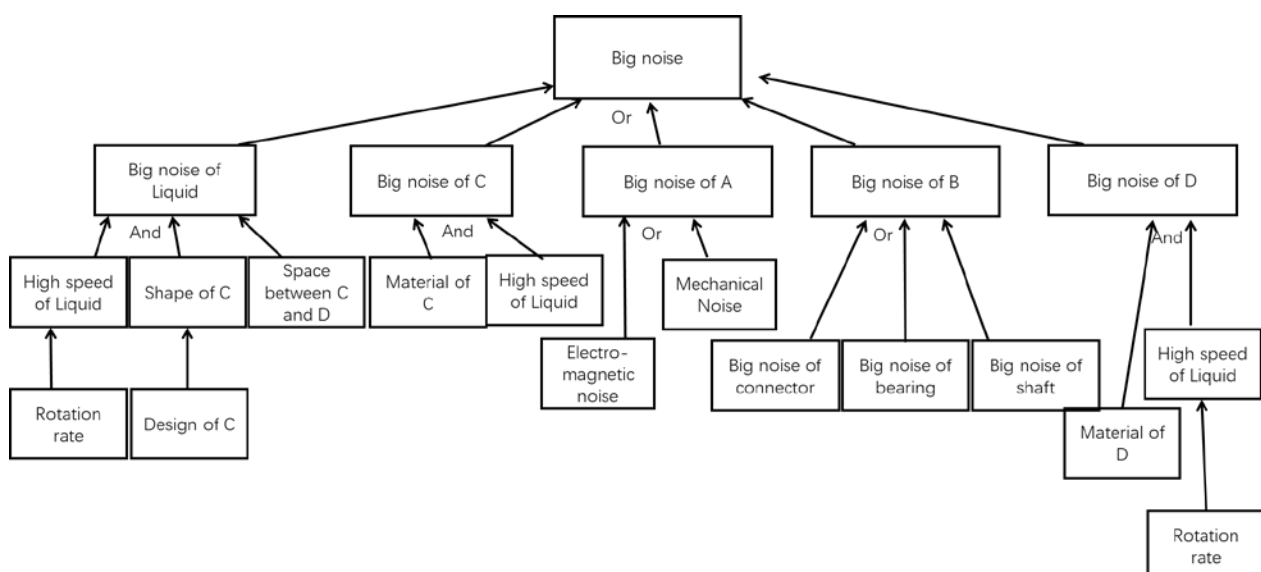


Fig. 4. First version of the cause-effect chain analysis

### 6.3 Candidate key problems.

Looking at the Cause-Effect Chain Analysis map, we come up with a long list of candidate key problems:

- Rotation rate
- Shape of C
- Space between C and D
- Material of C
- Mechanical noise of A
- Big noise of connector
- Big noise of bearing
- Big noise of shaft
- Material of D

It was a very long list of candidate problem. And it covered almost every component. While it is good that we could generate a lot of new ideas, the efficiency of solving the problem is quite low. So we further validated the key problems.

### 6.4 Design experiments to validate the key problems.

We designed experiments to obtain data to scientifically prove which ones were the key problems. The first data we gained was the noise level against the timeline of the working process. See below data:

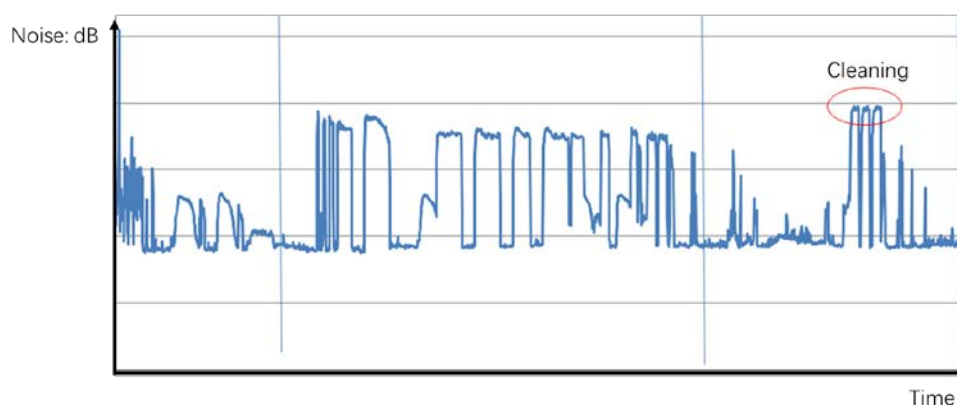


Fig. 5. Data of noise against time

Based on the data, the peak noise was in the cleaning stage. So we determined that the key problems should be related with cleaning. Then we performed the Cause-Effect Chain analysis again focusing on the noise of cleaning, which was very different. See below:

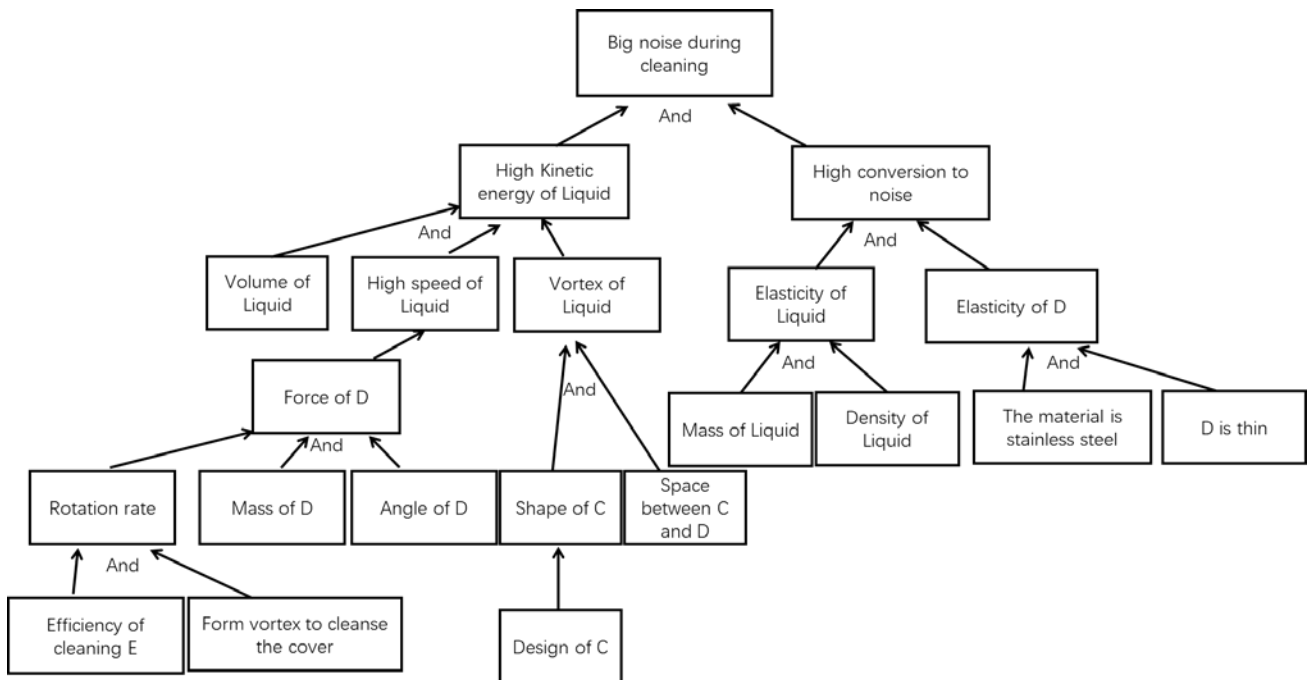


Fig. 6. Second version of the cause-effect chain analysis

From the analysis, we came up with a shorter list of key problems:

- Low efficiency of cleaning E
- Shape of C
- Space between C and D
- Elasticity of D

To further validate the key problem, we performed the experiment and to see which component was the major source of noise.

	Noise (dB)
Component A	<b>78</b>
Component A+B	<b>79.5</b>
Component A+B+C	<b>81</b>
Component A+B+C+D	<b>84</b>
Component A+B+C+D+Liquid	<b>88.5</b>

Fig. 7. Data of noise with different components working

Based on the following formula of noise, we could calculate the theoretic value of the noise of different component.

$$L_p = 10\lg(10^{0.1L_{p1}} + 10^{0.1L_{p2}})$$

And we got the following calculation:

	Theoretically Calculated Noise (dB)
Component A	<b>78</b>
Component B	<b>74.2</b>
Component C	<b>75.7</b>
Component D	<b>81</b>
Liquid	<b>86.7</b>

Fig. 8. Theoretic calculation of noise of different components

Based on the theoretic calculation, we determined that the key problems were related with C, D and Liquid.

While the key problems of 'Shape of C', 'Space between C and D', and 'Elasticity of D' were turned to design questions, the problem of 'Low efficiency of cleaning E' was still not that clear. So we further performed a Cause-Effect Chain Analysis on this problem. See below figure:

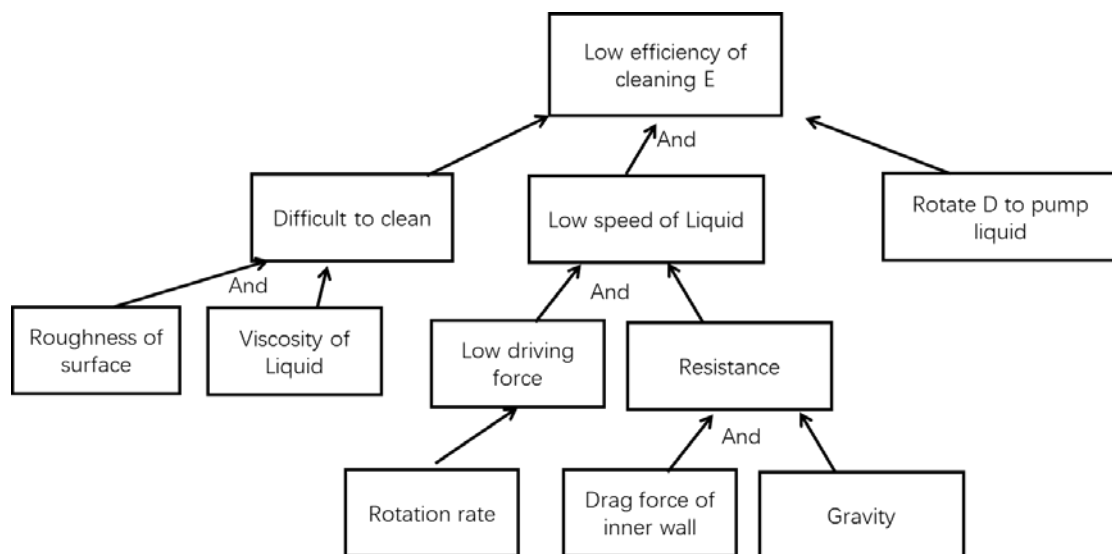


Fig. 9. Third version of the cause-effect chain analysis

When we had a closer look at the analysis, we found that there are 2 underlying key problems:

- A physical contradiction: the rotation rate needs to be high to have high cleaning efficiency, and the rotation rate needs to be low to have lower noise.
- We used the method of rotating D to pump water.

### 6.5 Validate whether the project key measures are already satisfied.

We further collect data to validate whether we could satisfy the key measures if we solved the problem. For example, if we set the rotation rate of D at half of previous value, the noise were significantly lower, and way more than the project objective.

### *6.6 Use problem solving tools to tackle the problems.*

Solving the physical contradiction of rotation rate was difficult. But we came up with very good solutions by thinking about what were the other methods of pumping water to clean the cover. Because there were already liquid, and when we added liquid into the machine, there was already a pump. So we add a nozzle onto the cover, and every time the liquid is added to the machine, the cover is cleansed by the liquid. So in the cleaning stage, we no longer use the component D to pump the liquid. Instead, we use the pump to clean the cover. So we could maintain the rotation rate at a very low level during cleaning, and the cleaning efficiency was quite higher. And the peak noise of the machine was reduced by 6 dB with this single solution. And then we further improved the system by solving the other key problems of 'Shape of C', 'Space between C and D', and 'Elasticity of D', and finally we reduced the peak noise by about 10 dB. And the new product was launched to the market in June 2018.

## **7. Conclusion.**

In the case study, after performing problem analysis, selecting and validating key problems helped us increase the efficiency of problem solving significantly. Instead of solving a list of 9 problems, we gained some data, and selected 4 problems out of 9, and then further focused on 1 out of 4. After solving the most important problem, then we started to tackle the other 3 out of 4 key problems we selected.

Instead of solving a long list of different problems, now we are able to identify the most important problem, and focus our energy on solving it. This makes it much more efficient in problem solving. When solving the problems, we only seek the solutions that are closely related with the key problems.

This paper opened a window to approach the key problems with a new perspective. Future study could be related with the linkage between technical key problem and business key problem. We need to bear in mind that technical key problem should be tightly linked with business key problem. Key problems in business are related with business strategy and customer needs. So future research should focus on how to select and validate key problems not only based on technology, but also considering business.

## **Acknowledgements**

This idea of this paper originated from a talk with Sergei Ikovenko when I took the level 3 certification program several years ago. At that time, Sergei explained what is a key problem, and I practiced it a lot in projects, and extended it into an algorithm.

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**Communicating Author:** [arthur.lok@innoenterprise.com](mailto:arthur.lok@innoenterprise.com)

## **TRIZfest 2018**

### **September 13-15, 2018. Lisbon, Portugal**

## **TRIZ IN SCHOOLPROJECT SENSUS**

Annemieke Vermeijlen<sup>a</sup> Christoph Dobrusskin<sup>b</sup>, Hans Baaijens<sup>c</sup>, Annemieke Vennix<sup>d</sup>,  
Carla Upperman<sup>e</sup>, Maritza Rovers<sup>f</sup>

<sup>a</sup>*Van Maerlantlyceum, Eindhoven, The Netherlands*

<sup>b</sup>*Philips Innovation Services, Eindhoven, The Netherlands*

<sup>c</sup>*Eindhoven, The Netherlands*

<sup>d</sup>*Heerbeek College, Best, The Netherlands*

<sup>e</sup>*Frits Philips Lyceum, Eindhoven, The Netherlands*

<sup>f</sup>*SensUs Organization, Eindhoven University of Technology, The Netherlands*

### **Abstract**

For about four years now Philips is supporting schools to help students to be more creative and inventive. In a number of projects training materials for both, students and teachers, are being designed, tested and improved. The current teaching materials are further developed by a teacher development team of several High Schools in the Eindhoven Region in the Netherlands with the intention of using it in various projects. One of these projects is “Developing a Biosensor for Medical Healthcare” in collaboration with the International SensUs Student Competition at the University of Eindhoven. This year the theme of the SensUs Student Competition is measuring antibiotics for better healthcare. The High School teams, using the TRIZ based approach described above, will design and propose a possible biosensor which that can help patients to receive the best possible treatments and help society in its fight against antimicrobial resistance.

Keywords: TRIZ, High Schools (K-12), Education, Teaching materials, students, SensUs, TRIZ pedagogy.

### **1. Introduction**

Nowadays it is very important for High Schools to prepare their students for future studies and jobs to focus on problems from real live, complex problem solving, critical thinking, creativity, collaboration and citizenship.

Problems from real live are found in Context-Based Learning (CBL) approaches used in secondary school science education in many countries to counter decreasing interest and low motivation for the subject [1]. These CBL approaches aim at developing attractive curricula for the science subjects, in which material is taught and organised from contexts focusing on the role of natural science subjects in society and further education [2].

However, almost no attention has been paid to complex problem solving, critical thinking and creativity, despite the importance of these skills in the context of the 21st century skills. Also, it is very difficult for High Schools to combine all these aspects in one project. Solutions are being sought in the form of extra education, special projects and programs for highly talented people.

Creativity is a skill that you can learn using creative thinking techniques. The importance of mastering creative thinking is that this skill can be used for innovative solutions to improve the quality of life on earth, and enjoy finding solutions to difficult problems be they technical or social in nature.

Often when faced with real life problems, the starting point is quite fuzzy, and therefore a problem analysis is needed to identify the underlying root causes and key problems. Furthermore, the “best” solution to a problems is seldom obvious. Here the solution is to first diverge in the creative process and to generate as many alternative solutions as possible. The best solution can only be determined at a later stage.

TRIZ as a way of thinking to improve the critical thinking and problem solving skills of school children has been used for many years, however most of these activities take place in Russia and are little known in Western Europe [3,4 ]. In 2014 Dobrusskin and Baaijens [5] started to introduce TRIZ based approaches for High Schools in the region of Eindhoven. They developed protocols to both qualify teachers and High School students leading to creative productivity in terms of unique ideas. One of the problem solving tools they introduced was a selection of 10 of the 40 inventive TRIZ principles [6].

The project described in this paper is the Biosensors project of SensUs. SensUs is an international student competition for biosensors at the University of Eindhoven. This year the theme of the SensUs Student Competition is measuring antibiotics for better healthcare. Every year, SensUs organizes a competition at The Eindhoven University in which university students present a design of a biosensor. This project will be a junior variant of this competition about the subject of biosensors. High school pupils will start designing a biosensor that can be of diagnostic value and that fits within the theme of SensUs. In order to do this, they first have to search for and process information before they share the newly found knowledge with their peers and build on it. This way of doing research is a process with which pupils and teachers in secondary education have little or no experience. To achieve this, the students followed the TRIZ lessons [7] leading to a large number of creative ideas.

## **2. Theoretical framework**

### *2.1. 21st century skills*

21st century skills are general skills and related knowledge, insights and attitudes necessary to function in and contribute to our future society. The following 21st century skills have been defined [8]:

- Creativity: inventing new ideas and being able to elaborate and analyse them.
- Critical thinking: being able to formulate one's own, substantiated vision or opinion.
- Problem-solving ability: Recognising a problem and arriving at a plan to solve it.
- Communication: effective and efficient transmission and reception of a message.
- Collaboration: jointly realising a goal and being able to complement and support others in doing so.
- Digital literacy: effective, efficient and responsible use of (information) technology. This includes ICT (basic) skills (including computational thinking), media literacy and information skills.
- Social and cultural skills: effective learning, working and living with people from different ethnic, cultural and social backgrounds.
- Self-regulation: achieving targeted and appropriate behaviour.

The first three 21st century skills are well reflected in the application of the TRIZ based methodology.

## *2.2. SensUs Competition*

SensUs, founded in 2015, started as an international student competition in the field of biosensing for healthcare applications. Each year, a continuously increasing number of international student teams work for ten months on a biosensor prototype, which they present at the SensUs Contest Weekend in Eindhoven in September. SensUs represents a highly innovative form of education geared towards multidisciplinary, goal-oriented, learning-by-doing engineering. The participating teams consist of students from multiple scientific disciplines. Biosensing technologies are inherently multidisciplinary. To be successful, the teams need to creatively combine molecular technologies and device technologies.

The mission of SensUs is to stimulate education and innovation in the field of biosensing. Each year, a societally impactful indicator of health is chosen as objective in collaboration with different stakeholders, like medtech companies and national medical bodies.

SensUs has provided the space for High School students to take part in their annual competition. These students can start research in the direction of biosensors outside of the normal curriculum and thus participate in the event. In 2017 for example, the intention for the pupils was to design a biosensor to detect biomarkers released when the heart fails and thus establish a diagnostic tool for heart problems. The pupils do the research themselves and ultimately produce a poster and a presentation for the event.

## *2.3. Assignment description*

Biosensors are small "devices" that can determine abnormal values of substances in a person's blood. When someone is ill, there will be certain specific substances present in the blood. Thus, by demonstrating the presence of these specific substances in the blood, one can assign or exclude certain diseases in a patient. An example of a biosensor is the device that diabetes patients use to measure their glucose level. A drop of blood is placed on the sensor, after which it determines the amount of glucose in the blood. The substance that has to be identified by the biosensor is called a biomarker, in this case glucose. Another example of a biosensor is a pregnancy test. When a woman is pregnant, a certain hormone is produced by the body. The biosensor tests for the presence of this hormone and can therefore give a positive or negative result. Biosensors therefore have various applications, many of which are already known to students, whether or not they are aware of them.

In this project pupils are going to investigate such biosensors. They will develop a concept for a biosensor aimed at a bacterium that can be eliminated by using the last resort antibiotic vancomycin, Methicillin-Resistant *Staphylococcus Aureus*, the so-called MRSA bacterium. First of all, an easy-to-use biosensor for this bacterium or for vancomycin is not yet on the market. MRSA causes unpleasant symptoms and can even be fatal without treatment. This bacterium makes a protein, PBP2a, that could be detected relatively easily. A biosensor that can detect this protein can therefore demonstrate the presence of this bacterium. The results of the biosensor will show whether or not the vancomycin administered has worked against the bacterium.

It is also a good example of bacteria that have become resistant to certain antibiotics. In the past, these bacteria could be treated with a kind of antibiotic, but have undergone mutations that have made them resistant to it. For example, MRSA has become resistant to the kind of beta-lactam antibiotics with penicillin as the best known example. Vancomycin is now the life-saving drug, but if it is not administered in exactly the right quantities. If the dose is too low, the bacteria will not be completely eliminated, which increases the chance that bacteria will develop resistance.

However, too high a dose of vancomycin is not good either, because the kidneys, among other things, will then be damaged. Since every human being is slightly different, everybody deals with antibiotics administered in a slightly different way. With an easy, user-friendly and fast biosensor, it is therefore possible to assess the extent to which the vancomycin has been administered correctly and if the concentration in the blood is acceptable.

Pupils will not only investigate which processes are relevant when detecting MRSA, the user-friendliness of a biosensor must also be taken into account and requirements must be drawn up for this. The pupils will also learn about the great social importance behind their biosensor.

The pupils have the freedom to determine the aim of the project, and also how deep they go into the science of biosensing. They will work according to a Design Based Learning system (DBL system), which means that they will design their own project. This teamwork method is often applied at the Eindhoven University of Technology (TU/e). In September the pupils will visit the SensUs event. Having worked on this project, students should be able to understand what the participating teams are presenting. They are also allowed to present their work with a poster and a short pitch, but they will not participate in the competition. To follow this module, pupils need the following prior knowledge: biology (immune system/antibody/antigen), physics (magnetism, optics), Chemistry (molar mass, amino acids, proteins) and Mathematics (differentiate).

The questions that the students typically answer include:

- What are the characteristics of the biomarker? What is the effect of this on the biosensor?
- What do you want to use the biosensor for, monitoring or diagnostics?
- Does this affect how the marker is to be measured? Does one have to prick blood?
- Does this 'measurement method' affect the size or type of the biosensor?

### **3. Method**

#### *3.1. Participants*

The students who participate in the project are the students who are looking for an extra challenge from 5VWO, typically 16-17 years of age. In total 18 students from two different High Schools in the Eindhoven region participate with the TRIZ program in the SensUs project. The intention is that they meet a number of times in small groups and in this way become acquainted with carrying out research and collaborating in a group outside the standard format of teaching. These students have no experience of using meeting structures, analysis and ideation techniques, carrying out literature searches or presentation techniques for projects in this context.

#### *3.2. The TRIZ lesson*

The students were instructed in some basic TRIZ based techniques. These lessons had the form of a separate workshop of 75 minutes, and followed the outline as described in earlier papers [7]. The theory introduction was 30 minutes and the problem solving of the case took 45 minutes in two rounds and was given by Hans Baaijens.

For the problem solving part, the pupils then got a selection of 10 inventive principles, chosen, based on the experience of teaching TRIZ at schools [5]. These principles are all both, broadly interpretable and easy to grasp. They comprise:

01. Segmentation
02. Taking out
03. Local quality

- 07. Nesting
- 10. Preliminary action/prior action
- 13. The other way round
- 15. Dynamics
- 17. Another dimension
- 22. Blessing in disguise
- 25. Self-service

## 4. Results

In the first part of the project, students had to gain information and knowledge about the subject, namely to create a biosensor to detect the MRSA bacteria as described in section 2.3. So Pbp2a must be measured in order to know how much MRSA there is. Then you know how many antibiotics need to be administered.

Secondly, the students identified the underlying problems by making an analysis of the problem situation through interviews with hospital personnel and studying the procedure. A number of problems were identified: too many blood pricks are necessary, it takes a long time before a result is known and the amount of medication must be adjusted to the blood outcome.

Also, one group of four students decided to focus on the human site of the sensor. They used the following research question: How to design a biosensor for patients with MRSA suitable for home use?.

When applying the TRIZ principles the group of four students came up with the following ideas:

- 01. (Segmentation); multiple biosensors in your blood, biosensor in steps (blood prick, platelet, blood outcome)
- 02. (Taking out); When you put a biosensor on the skin and take it off. How? Rope, Velcro, sewing on, elastic, pin type. Taking out blood prick, in your blood (in your body), saliva (if possible), on your skin.
- 03. (Local quality); Multiple functions in biosensor, result in app rather than in biosensor.
- 07. (Nesting); All components in a biosensor, all information in an app, biosensor in blood.
- 10. (Preliminary action); Receiving notification by measuring, pharmacy receiving notification for medication, degradable plates, notification for hospital if it is too serious. Place in the body for blood prick.
- 13. (The other way round); under the skin instead of on the skin, prevent instead of fight, good material so that skin does not irritate.
- 15. (Dynamics); Not a large, but a small biosensor, in your body flows through blood (possible problem).
- 17. (Another dimension); Multifunctional app on your phone.
- 22. (Blessing in disguise); Re-use old parts, use the picture more often, replace the plates yourself, perhaps get bored at home. For yourself but costs less money, time, effort of nurses.
- 25. (Self-service); Easy app (without help) small biosensor, no/less help needed.

Based on these ideas the group will now work out concepts based on the ideas created with the inventive principles of 07. Nesting and 03. Local quality, particularly focusing on designs accom-

modating human needs. At the time of writing this paper the group was still in progress with this step.

## 5. Conclusions

Using the TRIZ pedagogy approach by high school students in projects or design based research has significantly enriched the student's experience and project results. The TRIZ way of working acts like an umbrella supporting the teamwork and keeping together the different disciplines involved in solving the problem at hand. The structured way of working led to a systematic analysis of the problem and a similarly systematic exploration of the solution space. The problem has been approached from a multitude of different perspectives which led to the identification of a variety of completely distinct solutions. In summary, the approach leads to far more creative ideas compared to other groups, who are not using TRIZ.

## Acknowledgements

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**Communicating Author:** a.vermeijlen@gmail.com

## TRIZfest 2018

Lisbon, Portugal – September 13-15, 2018

### TAKING HUMAN FACTOR OUT OF EQUATION. A TECHNICAL REMEDY FOR A MANAGERIAL CHALLENGE.

Sergey Faer, TRIZ Master, Mark Barkan, TRIZ Master

#### Abstract

Many superbly designed, expensive projects fail due to a seemingly innocuous human mistake. This happens in every field of human activity – technical, administrative, social, etc. People will find a way to derail any technological process, to misread any instruction, and to circumvent any rule or standard.

Traditionally, the attempts to solve these problems are based on the proverbial method of sticks and carrots. And if that doesn't work? What do you do when you have exhausted every motivational resource and have applied the most stringent punishment measures? Yet, the



failures continue to stubbornly raise their ugly heads. What do you do as a manager? Find better carrots or more effective sticks? Soon you will cross into the area where costs become prohibitive.

How to create a situation where there is no need to control anything, because an error is not possible in principle?

A full proof solution for managing personnel in this situation lies in an unexpected direction ... We must find a **TECHNICAL REMEDY** for a **MANAGERIAL CHALLENGE**.

*Key words: human factor, fault free operation, management objectives, method of paradoxes*



## 1. Defining the Ideal Final Result – IFR

According to TRIZ Glossary, see <https://matriz.org/wp-content/uploads/2016/11/TRIZ-Glossary.pdf>, IFR is defined either as a TRIZ tool: A solution which delivers the result required without the use of neither material and energy resources nor associated costs. As follows from the laws of physics such a solution may never be achieved and therefore the concept of the Ideal Final Result serves to reduce the degree of psychological inertia during the problem-solving process by targeting a problem solver towards searching for a solution with the best ideality ratio; or: A model of a solution to an inventive problem formulated as a set of justified requirements towards the X-component as it is used as a part of the ARIZ process. So, how do we utilize this concept for a real life problem-solving project?

**For example, let's address the issues of quality control in a factory:**

- Quality at the source – workers control themselves;
- Next team monitors the quality of work of previous team;
- A defect found once will never be repeated;
- Subsequent operation instantly evaluates the previous operation;
- Control of any action is carried out continuously and by itself;
- Personnel, responsible for a defect, willingly pays a fine;
- Departure from a project process instantly manifests itself;
- Deviation from a project is not possible in principle, the project controls itself;
- It is not necessary to control anything or anyone, because a mistake is not possible in principle;
- And so forth.

One of these IFRs is universal and its application always leads to the most reliable solution – “it is not necessary to control anything or anyone, because a mistake is not possible in principle”. It is advisable to always attempt to satisfy this IFR first.

Below is a terrific example of this IFR.



On an assembly line, components are being packed into boxes. Packers are not robots, but humans. The box is closed at the end of the assembly line. It is very important that the box contains the correct composition of components; otherwise, the firm will lose money, reputation, customers... But infallible people are rare, at best. People get

sick, they may be sleepy, somehow distracted ... as a result, an error of sort is made, despite all encouragements and punishments to prevent such occurrences. This situation persisted until a beautiful solution was developed. It consisted of a new box shape, and a new order of packing. This way, if there is one component too few or one too many the box would not close at the end of the assembly line. An open box at the end of the assembly line is a “red flag” – something is obviously wrong. The box is put aside and later repacked correctly. Therefore, the box with a defect doesn’t fly to another end of the world and the company doesn’t incur losses.



So, what can we learn from this example? Instructions do not guarantee a fault free process/operation, a person will always find a way to circumvent them. And there is no a carrot or a stick which may surely prevent it. Surprisingly, high technology further aggravates human factor issues. Then, how can we achieve infallible reliability? Or truly productive marketing plans?

A full proof remedy for most of the management issues lies in an unexpected direction ... We need to look for a **TECHNICAL SOLUTION** for a **MANAGERIAL PROBLEM**.

## 2. More examples

Let us look at similar examples. Do you remember such posters: “Save water – turn off the tap!” “Save energy – turn off the light! “, “Save heat – close the door!”, etc.? These days there are sensors that do all this turning on and off as necessary. The sensors eliminate the need for these posters – all happens on its own.

Another example. A speed bump works better than all the warning signs or a threat of fine. The drivers slow down on their own.



In some cases, such solutions may be way too expensive. Then, we should look for a truly ideal solution for our business without introduction of any additional devices. Solutions that will create a situation where our employees, ideally, could not violate or upset anything in principal.

While we are looking for such solutions, we should evaluate technological and/or managerial processes, and then search for inexpensive technical solutions for elimination of the bottlenecks caused by a strong “human factor”.

In the process, we systematically accumulate typical solutions for various problems – simple and inexpensive.

For example:

- *we have developed the stunning unique offers for our stores for the holiday, but the stores do not offer them to shoppers for some reason;*

Solution: The unique offer should sell itself, without any help. The store visitors should literally bump their heads against the unique offer. For example, a balloon with the information about the offer hangs from the ceiling. If a shopper is interested in this offer, they will ask the seller.

- *There are some wonderful products in our insurance packages, but our agents sell only what is easy to sell and is profitable for them;*

Solution: various discounts are offered with the purchase of a certain product. Thus, a potential client may ask an agent about this product in hopes of gaining a discount.

- *We have developed new, more convenient check-in process into our hotel, and have notified our managers at the reception desk and our guests (through the media). But, in the end, the information was lost somewhere and did not reach the reception desk, which, understandably resulted in some angry guests;*

Solution: instead of waiting for the new regulation to be made a part of the instruction manual, print it on a simple cardboard two-sided sign and place it on the reception desk. The same information is on the both sides of the sign. Customers see it on one side, and reception managers see it on the another. Everybody has the same information.

### 3. Conclusions

While our results are very promising, we understand that more work is required to develop a viable methodology, supported by many case studies. which may be successfully taught to those, who desire to become proficient with finding technical solutions for soft, transactional, issues. To this end, we are working on a new book, devoted to this subject.

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Corresponding author: Mark Barkan [mbarkan@matriz.org](mailto:mbarkan@matriz.org)

## TRIZfest-2018

**September 13-15, 2018. Lisbon, Portugal**

### METHOD OF PARADOXES

For those who have mastered the basic concepts of classical TRIZ: ideality, IFRs, resources, contradictions.

Sergey Faer, TRIZ Master, Mark Barkan, TRIZ Master

#### Abstract

The method of paradoxes is an analytical tool for problem formulation. The modification and refinement of the tools of the classical technical TRIZ, in the process of solving non-technical problems, resulted in the development of this method.

The method of paradoxes proposes to formulate for an initial (problematic or ordinary) situation a number (10 to 20) of paradoxical problems. The quantity transforms into a new quality – although formulated in a unique way, every paradoxical statement is aimed at the same issue. This simplifies the process of arriving at the solution to the problem since we attack problematic situation from various points of view.

Presently, the method of paradoxes has been successfully applied (by us, by our colleagues, by numerous participants of the seminars and workshops) to many issues from different areas of activity:

- sales and marketing;
- PR;
- process related issues;
- quality management;
- personnel management;
- election campaigns;
- etc.

Key words: method of paradoxes, non-technical problems, *multiple problem formulations*

*A paradox is a statement that, despite apparently sound reasoning from true premises, leads to an apparently self-contradictory or logically unacceptable conclusion. A paradox involves contradictory yet interrelated elements that exist simultaneously and persist over time. Paradoxicality is unexpectedness, unfamiliarity, originality, self-contradiction, initial assumptions, generally accepted, traditional view or common sense in content and/or form.*

## 1. Introduction

Paradoxes have always been a part of our business and personal lives. In a nut shell, a paradox is a contradiction between seemingly independent elements. Yet, these elements are related in accordance with the dialectic law of the unity and struggle of opposites. Lately, paradoxes became a subject of research in organizational and management sciences. Schad, et al, (1), offers a comprehensive study on the last 25 years of this research. The study suggests that the “Paradox studies offer vital and timely insights into an array of organizational tensions.” However, the main emphasis is on paradoxes, which are inherent in various fields of human activities: sciences, managerial and organizational processes, as well as technological processes. In other words, most of the current research concentrates on revealing and defining existing paradoxes without so much as an attempt to resolve these paradoxes. In fact, many writers suggest that paradoxes can’t be resolved and, among other suggestions, advise top level management to balance paradoxes to ensure success of the companies they run. Compromise galore! In this paper, we will describe a process of formulating paradoxes, leading to solutions for an “unsolvable” problems.

## 2. How to formulate paradoxical problems?

Identifying a problem is sometimes more difficult than solving it. To bring about something worthwhile, it is necessary to stymie yourself, complicate the task. Only then will you break out into new frontiers and shift stereotypes and patterns. Paradoxes, then, are the problems, found on the front line. The issues of science, business, human relations, art ... anything. Someone will say that it is impossible to solve them. Great! Hence, there is a high probability that the paradox is not yet resolved by competitors and this direction may prove fruitful.

The method of paradoxes proposes to formulate for the initial (problematic or ordinary) situation 10 to 20 paradoxical formulations of problems. The quantity goes into quality - many paradoxes, though formulated differently, have the same goal. This facilitates the decision-making process since we are approaching a solution from different angles. At the moment, the method of paradoxes has been successfully tested (by us, by our colleagues, by numerous participants of our trainings) on tasks from different areas of activity:

- the issues of sales of goods and services (advertising, marketing, PR);
- organizational and technological issues;
- quality assurance;
- personnel management;
- election campaigns;
- etc., etc.

In this paper, we discuss two methods for creating paradoxes. Consider the situation: on the surface everything looks good. The conventional wisdom suggests: if it is not broken don’t fix it. However, to move forward, we need to break it and, then, fix it. Therefore, we need to formulate several appropriate problems. Not some trivial problems, but the ones that will force problem solvers out of their traditionally standard and conservative niche.

What kind of TRIZ tools are available today for problem formulation?

1. We can formulate several problems by defining an ideal object.

2. We can formulate several problems by applying IFR rules.
3. We can formulate problems by revealing contradictions.

In the process of solving non-technical problems some additional types of problem definition were developed. Some of them couldn't be obtained by using TRIZ tools. Others were easier to develop by means, other than by application of TRIZ tools. For example, let's try to apply the rule of ideality to a leaflet. An ideal leaflet, one that does not exist, but its function is executed. Yes, this leaflet is cheap, but, in many instances, this is not the main consideration. What is more important is that the leaflet contains a maximum of information, it is trust worthy, that it doesn't take much time to read, that the information stays current, etc. The formula of ideality can't help with the development of such ideal leaflet. The formula of ideality, as we know it, is not universal. And how a universal formula of ideality would look?

Let's consider this point...

A part/assembly is not there, but the function is performed ... so far so good: we don't expend material and energy, it has no mass, it doesn't cost anything, it can't break down. What is missing? The speed of the function performance, the quality of the function performance, the number of the additionally performed functions

Extended formula of ideality: the part doesn't exist, and the maximum number of functions is performed with high quality and without delay. Such formula forces the development of the comprehensive set of requirements for maximum performance level. This is a very important addition to the process of solving non-technical problems. The presented method of paradoxes helps to define a set of issues for achieving expanded ideality.

### **3. The first method for creating paradoxes.**

This method consists of five steps. The first step is the creation of tasks using traditional TRIZ tools.

The creation of paradoxes "from the disadvantages" occurs in the third step, after the formulation of the classical contradiction. The creation of paradoxes "from the advantages" occurs in the fifth step.

After the fifth step we should get the complete list of required tasks.

Step 1. Formulate the Ideal Object and corresponding IFRs.

Step 2. List all disadvantages: expenses, glitches, losses, etc.

Step 3. Formulate a contradiction for each disadvantage and elevate it to the point of absurdity.

Step 4. List all advantages.

Step 5. Elevate advantages to the point of absurdity.

Let's apply the paradox process to an ordinary leaflet. We have a task of creating a promotional leaflet, informing the potential customers about our client's products and services. As a rule, all the leaflets of the competing companies are similar in design and content. There is nothing unusual in them. Obviously, the effectiveness of these leaflets is quite low. Therefore, we need to create a leaflet that will rise above the competition. Where do we begin?

### Step 1. Formulate the Ideal Object and corresponding IFRs.

- The leaflet is not there, but its function is performed
- There is no text, but its function is carried out
- Leaflet produces itself
- People (the target audience) themselves dream up a leaflet's text for our benefit
- People themselves write a leaflet beneficial to us
- The leaflet is written by the nearest object of the super-system
- The leaflet distributes itself
- The leaflet is distributed by our clients
- The leaflet is distributed by the competition

### Step 2. List all disadvantages: expenses, glitches, wastes, etc.

Disadvantage	Paradox
People refuse to take leaflets	
People take leaflets, but throw them away	
People don't have time to read leaflets	
Message is without target	
Message misses target	
Distribution is too expensive	
Information is static	
Low efficiency of reaching the target audience	

### Step 3. Formulate a contradiction for each disadvantage and elevate it to the point of absurdity

Disadvantage	Paradox
People refuse to take leaflets	People are reluctant to take leaflets, but our leaflet is in great demand, people demand it.
People take leaflets, but throw them away	An ordinary, inexpensive leaflet, but no one will throw it away.
People don't have time to read leaflets	It is as complete as possible, but it is read in a flash.
Message is without target	The message is the same for everybody, but is addressed to everybody individually



Message misses target	The contents of the leaflet are the same for everybody, but everyone sees something important for them individually.
Distribution is too expensive	People distribute the leaflets on their own without any encouragement
Information is static	Nothing bad has happened yet, but the leaflet already protects against it.
Low efficiency of reaching the target audience	We give the leaflet to everyone, but it only gets to the target audience

#### Step 4. List all advantages.

Advantage	Paradox
Carries useful content	
Stimulates buying	
Contains contacts	

#### Step 5. Elevate advantages to the point of absurdity

Advantage	Paradox
Carries useful content	The information is so useful that people spread it by the word of mouth
Stimulates buying	The leaflet forces everybody to look at the listed contact, then to make an inquiry and to buy.
Contains contacts	Contacts from this leaflet are impossible to forget.

The process of solving the resulting problems may lead to unexpectedly beautiful ideas. It should be noted that among these problem definitions we find traditional TRIZ based descriptions of the ideal object and IFRs (8 problems), as well as the descriptions obtained while applying the Method of Paradoxes (12 problems).

These problems are as follows:

1. The leaflet is not there, but its function is performed
2. There is no text, but the function is executed
3. The leaflet writes itself
4. People (the target audience) themselves dream up a leaflet's text for our benefit
5. People themselves write a leaflet beneficial to us
6. The leaflet is written by the nearest object of the supersystem
7. The leaflet distributes itself
8. The leaflet is distributed by our clients
9. The leaflet is distributed by the competition
10. People are reluctant to take leaflets, but our leaflet is in great demand, people ask for it
11. An ordinary, inexpensive leaflet, but no one will throw it away

12. It is as complete as possible, but it is read in a flash
13. The message is the same for everyone, but is addressed to everybody individually
14. The contents of the leaflet are the same for everybody, but everyone sees something important for them individually
15. People distribute the leaflets on their own without any encouragement
16. Nothing bad has happened yet, but the leaflet already protects against it
17. We give the leaflet to everyone, but it only gets to the target audience
18. The information is so useful that people spread it by the word of mouth
19. The leaflet forces everybody to look at the listed contact, then to make an inquiry and to buy
20. Contacts from this leaflet are impossible to forget

#### 4. The second method for creating paradoxes.

The easiest way to create a paradox is to use the formula: "the worse, the better" (this is some simplification of the third step of the algorithm in the first method). Thus, we force ourselves to use the Inventive Principle #22, "Blessing in Disguise" or, literally "convert harm into benefit", as often as possible.

This method is performed in three steps:

Step 1. List all disadvantages: expenses, glitches, losses, etc.

Step 2. Form a conflicting pair (there can be several of them) - we determine what is inevitably worsens, if the disadvantage is enhanced.

Step 3. Link the conflicting pair in accordance with the formula "The worse, the better". It is desirable to enhance the absurdity of the formulation, bringing the disadvantage and advantage to the limit.

Let us demonstrate how this method for creating paradoxes works on the example of paradoxes stemming from managing an organization.

Step 1. List all disadvantages:

Disadvantages	Paradox
Salary is insufficient for motivation	
Nobody wants to do difficult task	
The team does not like the task assigned	
There are no Career Opportunities	
People get tired quickly	
Internal competition destabilizes the team	
The team is psychologically unstable	
Low level qualification of the personnel	
High salary expenses	

## Step 2. Form conflicting pairs

- Low salary - the desire to work (motivation)
- Difficulty of the task - enthusiasm (motivation)
- Uninteresting task – effort (motivation)
- Lack of prospects – enthusiasm (motivation)
- Fatigue - productivity
- Internal competition – tense atmosphere
- Psychological incompatibility – tense atmosphere
- Qualification - outcome and quality of work
- Number of employees – the volume of products and work performed

## Step 3. Formulate paradoxes

Disadvantages	Paradox
Salary is insufficient for motivation	The less we pay, the more the employees want to work
Nobody wants to do difficult task	The harder the task, the more people are willing to do it with great enthusiasm
The team does not like the task assigned	The more the team dislikes the task, the better it is performed
There are no Career Opportunities	The fewer opportunities for personal growth, the higher is the level of personal motivation
People get tired quickly	The more people work, the more they are relaxed and the better they perform their duties
Internal competition destabilizes the team	The higher the internal competition, the better the atmosphere in the team
The team is psychologically unstable	The more people are different and psychologically incompatible, the more cohesive the team
Low level qualification of the personnel	The lower the qualification of employees, the better the result of their work
High salary expenses	The number of employees is decreasing, yet the volume of work performed is growing

Note. The typical error of those who start using the Method of Paradoxes, they create a paradox by the formula: "The better, the worse." For example, "the better the management - the worse the result". Anti-paradoxes like these make no sense. (Better sense makes a paradox: the worse the management, the better the result).

Then, the list of problems is as follows:

1. The less we pay, the more they want to work
2. The harder the task, the more people are willing to do it with great enthusiasm
3. The more the team dislikes the task, the better it is performed
4. The fewer opportunities for personal growth, the higher is the level of personal

motivation

5. The more people work, the more they are relaxed and the better they perform their duties
6. The higher the internal competition, the better the atmosphere in the team
7. The more people are different and psychologically incompatible, the more cohesive the team
8. The lower the qualification of employees, the better the result of their work
9. The number of employees is decreasing, yet the volume of work performed is growing

To the resulting list of paradoxes, we must add traditional TRIZ-formulations of the ideal object and IFRs. Usually, this list consists of 20 to 50 paradoxes. In the end, we get a list of problems, the solution of which may lead to unexpectedly beautiful ideas. Searching for solutions is especially effective by a team of 5-6 persons in a brainstorming mode.

### **Two important recommendations:**

- 1) An in-depth understanding of TRIZ problem solving tools must precede the training for Method of Paradoxes. Then the participants have no fear of paradoxes, and they calmly formulate them and move to the solution stage
- 2) The paradoxes may be developed by a person working alone, however, solving them, especially for the first time, is best in a team following brainstorming process.

For typical situations paradoxical problems may be created in advance. For example, we can develop a common list of paradoxes for:

- a typical store, bank, innovative campaign, poster presentation...
- quality assurance process for a firm, educational process...
- paradoxes for a process of selling goods and services...

In the appendix below you can see paradoxes formulated for various situations.

Below, in the Appendix, are some examples of paradoxical problem formulations.

Method of Paradoxes is a certain approach to problem formulation process. As we said at the beginning of this paper, defining a problem is often more difficult than solving it. The application of the method of paradoxes allows for the formulation of the problem from many different vintage points. As a result, we produce a whole array, a set of problems that may lead to a beautiful solution from several different directions.



*"And now, the main paradox - all unsolvable paradoxes are solvable. It is difficult, but possible. If it were easy, then everybody would have done so for a long time. But everyone does what is easy or copy the pioneers. If you want to win in a competitive race, do what no one has done before – solve your paradox."*

## 5. A couple of examples

### Paradoxes Related to Quality Assurance Issues

Quality assurance is usually perceived as an area that requires tools and procedures for control – for this you need to allocate employees, pay them salaries, buy supplies ... No! We demand that quality assurance is carried out in an "ideal way" – that is, without any expenditures on our part. People/processes control themselves, we only need to provide know-how.

One of the problems arose at the workshop for the field trailer manufacturer. The factory produces comfortable trailers on wheels, used by various field personnel – power engineers, oilmen, etc. The technological process consists of many operations, which are dispersed in 11 shops. The product is consistently relocated from one shop to another, where more and more parts are added. At any time, a defect may be allowed. This defect is often noticed only at the end of the process when it is too late to fix. Therefore, such trailer is sold at a significant discount. As a result, the company losses money and reputation. The workshop participants formulated paradoxical problems as directed by the Method of Paradoxes. Some of them, in fact, are ready-made solutions.

The paradoxes:

1. The workers control themselves – quality at the source.
2. The next team monitors the quality of the previous team's work.
3. Once found defect is never repeated.
4. The following operation immediately evaluates the previous one.
5. Quality is continuously evaluated by buyers (those who are most interested).
6. Control of any action is carried out continuously and by itself.
7. Those, who caused a defect, gladly pay a fine on their own initiative.
8. No mistake, at any work place, can harm the following operation in principle.
9. Every deviation from the specifications instantly declares itself.
10. It is impossible to deviate from the specifications – the specifications protect themselves.
11. No need to control anything or anybody – the mistake is not possible by definition.
12. All consecutive operations are performed simultaneously - the defects do not "accumulate".

From a number of ideas, triggered by the paradoxical problem formulations, the team selected the strongest two, based on the following criteria: it is simple and can be readily implemented without a delay, it does not require any additional expenditures.

1. The solution for a paradox **"The next team monitors the quality of the previous team's work."** – if a team discovered a defect it receives bonus at the expense of the team, responsible for this defect. Thus, the company owner solved quality assurance issue without spending any money.
2. The solution for a paradox **"Those, who caused a defect, gladly pay a fine on their own initiative"** – the introduction of a progressive fines scale.

If the employee, responsible for a fault, admits to it on their own, then the initial fine is small. However, every next fine is larger. But if the employee concealed his fault and it was discovered by someone else, then the fine is very large, Thus, it pays to admit your own mistake.

### **Paradoxes related to a booth at the conference**

Professional exhibition - a great event for sellers of goods and services, this is the moment of maximum concentration of the target audience. But this is also the moment of the greatest competition: all pros are gathered in one place, many offer the same goods and services. Each company wants to draw attention to its booth, so that visitors to the exhibition do not pass by without a notice, somehow make the booth to stand out ... And how can we make everyone attracted to us, even though we have a small booth in far end of the exhibition hall? Or make all visitors advertise our product. And it will be better yet if our competitors advertise us ...

Let's formulate a few paradoxical problems:

- All visitors to the exhibition start advertising our booth and invite their friends to it
- We do not specifically urge anyone, but as soon as attendees enters the exhibition hall, they immediately go to our booth
- Visitors plan to see our competitors, but come to us
- Our booth doesn't cost much, but appears expensive
- The entire exhibition is our booth
- It take a second to tell the visitor all about us
- We are not sponsors, but the exhibition is held under our auspices
- The booth is the smallest, but it is also the most noticeable
- We don't have a booth, but everyone knows about us
- Our competitors tell us how wonderful we are
- Visitors, without any effort on our part, ask million questions about our product
- Every visitor believes that they were always familiar with our company
- No information is available, but the client is fully informed
- The visitor takes from the stand exactly what he needs, and does not take anything in excess
- We don't have or offer anything, but everyone wants to take this from us
- The fewer people are at the booth, the more visitors know about us
- The exhibition is not on our topic, but we are the most in demand
- There are no employees at the booth, but presentations are being conducted
- The booth itself talks to visitors
- All visitors at the exhibition willingly advertise our products
- None of the visitors complete our questionnaires, but we have information about every visitor
- All the spots at the exhibition have already been reserved, but we are offered the best spot
- We do not turn anyone away, but our visitors are only those who are ready to buy from us
- We don't have enough handouts, but every visitor has them
- We do not have a product, but it is sold and it can be tried
- ...

### **An example of application**

Paradox: "All visitors at the exhibition willingly advertise our product".

The first day, the exhibition is opened. Every vendor is trying to hand out their stuff: catalogs, business cards, booklets, souvenirs, baseball caps ..., as attendees file in. All this stuff is promptly put away into tote bags. But your company, in the first half hour, after the exhibition is opened, hands out one flower on a short stem in a clear plastic vial. Liquid in the vial is supposedly special,

keeping the flower fresh for longer. A vial with a liquid can't be put in a bag - the liquid may spill. So, someone puts the flower in the breast pocket of the jacket, some hold their flower in their hands and a smile on their lips. As a result, half an hour after the exhibition is opened, all guests have flowers, all are in a good mood. But at some point, each of them notices a booth of a company, where an image of this flower is on display for everyone to see. A flower is the logo of this company. And people understand that all participants of the exhibition became advertising agents for this company, and the whole exhibition turned into one huge booth.

### **Paradoxes of recruiting and training new employees**

- We don't advertise a job, but everybody is aware of it
- Everybody may see our job wanted ad, but only those, we need, respond
- We don't interview candidates, but only suitable ones remain
- If a candidate is not suitable, they leave on their own without delay
- We don't train new employees, they acquire necessary knowledge on their own
- New employees take time away from the old ones, but insist on training new employees
- We don't invest into an educational system, yet it functions
- We are ready to spend on educating every new employee, but they refuse this expense
- We only trained one employee, but everybody acquired necessary knowledge
- The acquired knowledge is immediately put to
- Obsolete, ineffective knowledge removes itself
- The higher is an employee's qualification, the more profit they produce and the lower pay they demand

Let's examine a paradox: Everybody may see our job wanted ad, but only those, we need, respond.

An example of a solution: in 2004, above highway 101 in California, there appeared an interesting billboard, here's the content: {First 10-digit prime in consecutive digits of e}.com. It was a mathematical puzzle, a correct solution of which leads one to a site owned by Google. The puzzle itself is quite simple for any competent programmer. After you got on the site, you were offered to solve several more complex problems. And the answer to one of them was: "The important thing that we learned while creating Google – it's much easier to find someone if he/she simultaneously searches for you. We need the best specialists in the world. That's why you are here".

### **Paradoxes of advertising, marketing and sales for new products and services**

- We don't advertise, but everybody knows about us
- The higher is the price and fewer discounts, the larger is the desire for our product
- We don't advertise, but we have many clients
- Competition/celebrities/the general population don't know about us, yet they help us
- We demonstrate our strengths without any expenses
- We provide discounts without any loss, the clients appreciate this
- Clients appreciate us forcing them to promote our brand
- The product itself talks to clients, provides information and motivates buying decisions
- Those, trusted by our potential clients, help with disseminating information and sales
- Our company is virtually unknown, yet everybody wants to buy from us

- Clients promote our product/service/firm without any effort on our part
- Buyers instantly share their shopping experience with everyone they know

## **6. Conclusions**

Artificial systems behave in very different ways. Same could be said about the predictability of their behaviors. Mechanical systems are the most predictable, electric/electronic are not as much. And various managerial, “soft”, systems are mostly unpredictable in their behavior. Therefore, somewhat different problem-solving tools needs to be developed for dealing with “soft” systems. The Method of Paradoxes is a very productive problem-solving tool. It was developed in the process of solving really tough “soft” problems. In order to master this tool, you must not be afraid to define the most ridiculously sounding problem formulation. The crazier it sounds, the better chance for a beautiful solution to a really tough problem. And one more note, you can’t become proficient with this method by reading about its application. You must attempt to solve as many real life “unsolvable” problems as you can put your hands on.



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## Appendix

### Selected Managerial Paradoxes

Paradoxes are grouped according to the conflicting pair, where, by improving one thing, we get the deterioration of the other.

#### ***Motivation of employees – productivity and quality***

(If we vigorously motivate employees, they increase productivity and improve quality, but our costs, usually, go up)

1. Zero motivation, yet the work is performed enthusiastically.
2. We don't pay, but everybody is eager to work. The lower is pay, the stronger is the desire to work
3. The more difficult/unpleasant the task, the more people are willing to do it, the more enthusiasm
4. The more boring the work, the more interesting it is for people. Attractive routine.
5. The team is unhappy about a task but performs it nonetheless. The higher is the level of unhappiness, the better is performance
6. The fewer prospects for growth, the better people are motivated

#### ***Comfort of employees – productivity and quality***

7. The more done, the less fatigue. The more people work, the more they are rested
8. The staff itself asks for tougher working conditions in order to improve the result

9. People manufacture only run-of-the-mill, familiar products, yet they actively develop

***Team atmosphere – productivity and quality***

10. The higher is competition, the better is team atmosphere
11. The more people are different and psychologically incompatible, the more cohesive is the team
12. Personal relationships are maximally developed, but all decisions are based on objective criteria
13. Everybody freely express their emotions, but no one is offended, and this does not interfere with work

***Management***

14. Nobody is praised, but everyone feels embolden
15. The approach is standard for everyone, but everyone feels individually encouraged
16. Does not make special effort, but is aware of all the important news (without help)

***Excess/shortage of resources (facilities, equipment, supplies ...)***

17. Resource is limited, but everyone has enough of it
18. Every resource is used by everyone, at any time, but there are no queues to it
19. There is no resource at all, but everyone uses it as needed

***Qualification of employees - quality of products/services***

20. High quality work is performed by unskilled employees
21. The lower the qualifications of employees, the better the result
22. We hire young and inexperienced people, and they work like "double-dyed"

**Control and information - organization and order**

23. We do not control anyone, but everything goes according to plan
24. There are no rules, prohibitions, instructions and controls, but no one violates process
25. No one is given an assignment, but everyone is engaged in the right task
26. Authority and tasks assign themselves to the staff
27. No information is available, but everyone is instantly aware of all the important developments
28. No one organizes documents, but everyone can find everything they need
29. Zero time is spent on clerical work, but all documents are in order
30. No one is accountable to anyone, but the interaction is in place
31. We do not assess anybody's effectiveness and do not make any inferences, but slothful employees leave the company on their own
32. The larger the network, the more precise the implementation of standards

***Expenditures – results***

33. The less effort we apply, the better the result
34. Work has not started yet, but the result has already been achieved

- 35. Everybody is resting, but work is going on
- 36. Employees pay employer for the opportunity to work

***Staff recruitment***

- 37. We are not looking for anyone, but those we need come to us
- 38. Suitable candidates themselves want to work with us and find us, and unsuitable stay away
- 39. People leave the company, but their contribution to our projects continues
- 40. A person quit, but still helps our business
- 41. The number of employees is decreasing, but the company's capabilities increase

**TRIZfest 2018**  
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**AUTOMATING TRIZ FOR CROWDSOURCING APPLICATIONS**

Aleksei Ruin<sup>a</sup>, Andrii Konovalenko<sup>b</sup>

<sup>a</sup>*Aleksei Ruin, Brussels, 1200, Belgium*

<sup>b</sup>*Andrii Konovalenko affiliation, Dnipro, 49100, Ukraine*

**Abstract**

Artificial Neural Networks (ANN or simply NN for neural networks) demonstrate good results in various tasks related to classification, clustering, forecasting and others. These days ANN have been occupying more and more creative niches as well: from canvas painting [1] and music composing [2] up to playing Go [3] and forecasting stock quotes [4]. It will be no surprise if sooner or later NN will step into “pure” ideation domain which is about creating ideas for a wide range of various tasks originating from different industries.

Authors propose to use a well-known approach to innovations based on looking for similarities [5] in another context: instead of looking for the similar product ideas, or in other words, creative endeavour results which can be used for improving the initial product, we propose to look for the similar problems which, strictly speaking, can lead to a very different invention not even looking like analogous.

A NN is proposed as the means for classifying these problems into one of the 25-30 categories similar to the Theory of Inventive Problems Solving (TRIZ) inventive principles. Once the problem categories are defined a topic modelling exercise can be done on an unstructured patent dataset. This exercise can use both the key words from the initial problem and the words from the selected inventive principle. These two contradictions should ensure that only the strong ideas will be returned.

Keywords: Crowdsourcing, Artificial Intelligence, Neural Network, Theory of Inventive Problems Solving, TRIZ, Inventive Principles.

**1. Introduction**

In fact the title conceals two important tasks: automating some of the TRIZ tools, for the sake of simplicity only the Inventive principles will be reviewed and applying them in one way or another to a crowdsourcing environment.

This research has been executed with one holistic goal: improving the crowdsourcing efficiency by putting part of ideation up to software. Ideally software should either replace human beings in solving technical and non-technical tasks or at least propose “a direction” which humans should organize ideation in, presumably resulting in higher submitted ideas quality and less time spent.

Authors do not limit the research to a specific type of tasks, be it the engineering tasks or non-technical. As it will be mentioned below the NN training dataset includes all the type of tasks usually appearing in a crowdsourcing environment. The examples are indicated in the Discussion section of the article.

*1.1. Automating TRIZ tools*

In this particular research we will be dealing with one tool only – Inventive Principles application. However other ideation tools like Feature Transfer or Trends of Engineering Systems Evolution can be automated in a similar way.

We strongly believe that Inventive Principles belong rather to human cognitive sphere than to the engineering systems or patents or anything following the ideation process.

Quite some of the Inventive Principles can be grouped up in larger and more generic categories. It is obvious that, for example, “Local Quality” principle and “Taking Out” are describing very similar approaches.

This is the reason why the number of analysed principles will be reduced to 25-30 of the most generic ones and only 10 will be used as an early trial. Strong oxidants, Composite materials, Thermal expansion and others of the similar quality will not be used.

Authors propose a slight modification of the Clone Problems application approach which was developed by G. Altshuller in the 80s and was further developed by S. Litvin in the 90s [6] and is based on deep non-obvious analogues among solutions that address the same physical contradiction. What we propose to modify can be summarised by:

- Unlike Clone Problems application tool we are not really interested in knowing which kind of a physical contradiction(s) is actually hidden in the analysed problem with a known solution,
- However we have to clearly identify which Inventive Principle(s) has been used for solving a problem,
- we postulate that if a new problem without a “control/known solution” is categorized by a NN the same way as a problem with a known solution then apparently it will “cry” for the same Inventive principle to be used for its resolution.

For ease of understanding the proposed algorithm is depicted on Fig. 1.

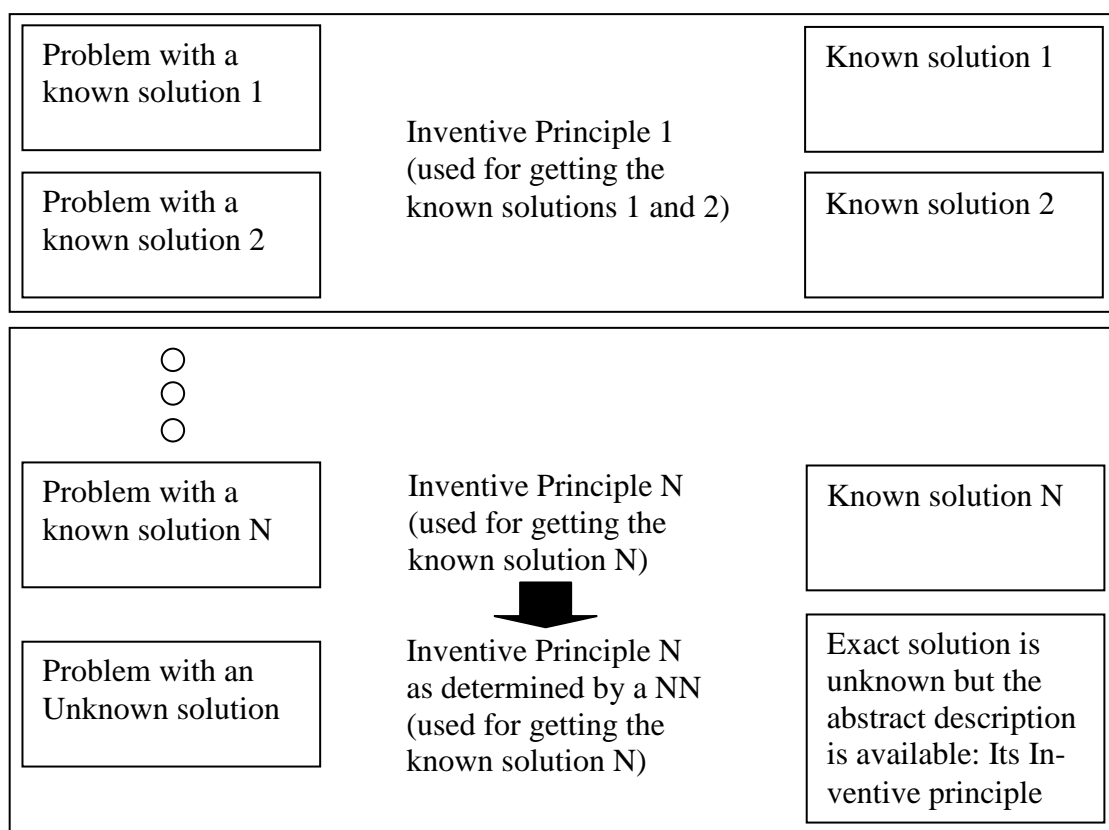


Fig. 1. Modified Clone Problems application approach

After having categorized a problem into one of the 25-30 groups we need to start searching for solutions. In order to ensure that the solutions will be brought in the TRIZ context we propose to build the search image by mixing the key words from the detected Inventive principle and some industry specific key words (if a user wants to have solution proposals originating from the same domain as the initial problem does).

The categorization task will be solved by a Recurrent neural network with a supervised learning and solutions search will be done by topic modelling. These two steps will be covered in detail in 1.2.

### *1.2. Using ANN for ideation support and Topic modeling for proposing solutions*

The strategy we wanted to use could be summarized in two simple steps which have been already mentioned in the Introduction as the tasks behind the article title.

First, we create (if it cannot be found) a crowdsourcing problems dataset. Organize a supervised learning and feed the dataset to the NN. Measure the classification accuracy. Run a trial sequence of new data which never participated in the learning. Measure accuracy again.

Second, after having defined which inventive principle a problem “wants” to use for its resolution we propose to run an NLP patent search, or any other knowledge database search, which can use  
a) only the key words from the inventive principle formulation returning “open innovation results”  
b) add the industry specific key words which will bound the search results to the domain the problem originates from.

## **2. Related work**

Zhen Li and Derrick Tate [7] used a similar mechanics for solving a different problem. These authors used Natural Language Processing (NLP) for defining functions hidden in a patent (design intention) and determining its level of invention in TRIZ language. It has been done via part-of-speech (POS) tagging and probabilistic parsing. For those not familiar with these technologies we would simplify POS tagging and quickly explain it as automated defining which part of speech every word represents. Now, by combining the verbal phrases and corresponding objectives, the authors found the functions which a patent is containing. ANN with supervised learning on a relatively short sequence has been used for defining the levels of invention.

In his research [8], Mehdi Akbari, proposed to use TRIZ, to be exact the Inventive principles, for creating a knowledge database for the AI-based software systems which later on can be used as an information source for automated ideation.

Tom Hope, Aniket Kittur and others in [5] are solving the problems similar to the ones in [7]. These authors also try to define the functions hidden in the patent descriptions to understand the purposes of the described products via a bidirectional recurrent NN. Having defined the functions they link analogies and propose ideas for innovations. I.e. “it enables core analogical innovation processes such as re-purposing: For a given product (such as a kitchen-sink cleaner) and its purpose, finding another way to put it to use (cleaning windows)”. Later on these analogies are proposed to a number of people or, generally speaking, to a crowd, as a creativity enhancer tool.

Alex Gaunt, Diana Borsa, Yoram Bachrach in [9] used a supervised deep NN for aggregating crowdsourced responses. It can be summarized as a typical “who wants to be a millionaire” ask the audience situation. The audience/crowd proposes some answers and the NN should “understand” which one of them is really right (it is not always the majority vote). They have successfully applied their NN to a standard IQ questionnaire so that it demonstrated “superior performance over existing methods”.

In [10] Gaetano Cascini, Davide Russo researched a similar problem of automatic patented invention motivation and internal product “mechanics” discovery. However this research also included an interesting aspect – automated Level of invention [11] estimation.

Janghyeok Yoon, Kwangsoo Kim in [12] solved another task, namely the automated identifying of TRIZ evolution trends from patents with similar method of test analysis. This has been achieved by extracting binary relations of the “adjective+noun” or “verb+noun” forms from patents using NLP, defining a “reasons for jumps” rule base that arranges trend-specific binary relations for trend identification, and determining specific trends and trend phases by measuring semantic sentence similarity between the binary relations from patents and the binary relations in the rule base.

Christopher Adams, Derrick Tate in [13] solved yet another task but with very similar methods of NLP. They defined not only a patent level on invention but also Ideality level of a patent. The latter has been performed with a NN which did the patent levels classification.

Work [14] deals with the task most relevant to the current research. Chung-Kai Tseng and others tried to classify the patents based on the TRIZ engineering contradictions hidden in them. They proposed to make this classification by using the engineering parameters the contradictions contain [15].

In [16] a very generic algorithm for Implementation of TRIZ for Automated Decision-Making is proposed.

Having reviewed the presented works we see that there is distinct trend towards TRIZ automation which has been also noticed by Valeri Souchkov and called TRIZ 2.0 features in [17].

The most popular solved problem is a problem of patent classification or using a wider term, knowledge database classification, which is often done by NLP methods therefore the AI approach proposed in the current work seems to be novel and quite relevant.

### 3. Experiment

The generically stated question we wanted to research was “can a problem statement contain the hints on which inventive principle it “wants” to use for its solving”.

We have used Python and machine learning framework Google TensorFlow [18] for building a recurrent neural network.

Unfortunately we were not able to find an available crowdsourcing problems dataset so we had to prepare it ourselves. The synthetic dataset we have made contained 500 various problems formulated in various ways in English and representing 10 Inventive principles (50 problems per principle):

- Segmentation
- Taking out
- Local quality
- Merging
- The other way round
- Nesting doll
- In-advance “cushioning”
- Intermediary
- Self-service
- Copying

For example one of the crowdsourcing problems “for” Segmentation was “Every time we have a party we face the same problem - we do not have all the needed glasses. For whisky, for champagne, for vodka - all that requires separate kind of glasses but it is too expensive to have all of them and, again, you need to have huge kitchen to store them. Can you propose a glass design which would fit all those beverages and still could be easily stored in a compact way?”

The control solution for this problem is a Sherwood Forlee's wine glass which unscrews at the top of the metal stem which then allows for easier storage of the glass portions. The user can also choose the right glass portion to fit drink choices. The metal stem adds extra strength and comes in a variety of colours and finishes. A rubber gasket at the top of the stem ensures snug fits [19].

All the 10 Inventive Principles have been accompanied with the control solutions in a similar way to Segmentation example above. Authors understand that there could be more than 1 control answer to any problem and there could be more than 1 Inventive principle “hidden” in every problem however for the sake of simplicity we have decided to do it in “one control solution per crowdsourcing problem” way.

We have trained the NN with 470 data entries (out of the mentioned 500 ones) and left 30 problems for measuring the NN classification accuracy. It turned out that accuracy was 67%. However we need to remember that it is a “perfect” accuracy reached on the training dataset samples only. Real accuracy will be of course lower.

When the NN has been fully trained, we fed it with 6 trial crowdsourcing problems which have never been mentioned in the learning dataset. All of them had the control solutions as well. They were completely new to the NN (new words, new expressions, non-engineering systems mentioned) and the intention was to see if the NN could properly classify them and define the hidden Inventive principles which these problems “wanted” to use for its effective resolution.

Despite the training dataset was more than modest, the results of this trial were quite remarkable and are discussed in the section 4 of this work.

## 4. Discussion

As we have already mentioned the NN used 6 realistically formulated crowdsourcing problems (crowdsourcing campaign entries) which had the control answers indicated in the Table 1.

Table 1

NN trial sequence

Crowdsourcing problem number	Control solution Inventive principle	Inventive principle as the NN “feels” it	Hit/Miss
1	Segmentation	Merging	+ - (*)
2	Taking out	In-advance “cushioning”	-
3	Local quality	Coping	-
4	Merging	In-advance “cushioning”	-
5	The other way round	The other way round	+
6	Nesting doll	Merging	+ - (*)

(\*) Further discussed below

### 4.1. Segmentation vs. Merging

The task formulation we used was “We have been manufacturing the cartridge razors for almost two hundred years. They are very sharp, very reliable and have a long service life. The problem our customers keep complaining about is the fact that they have to shave the same skin area a few



times till all the bristles are removed. This provokes skin irritation and should somehow be eased. Can you please propose a new cartridge razor design which would shave away all bristles at one move?” The obvious solution is placing a few razor blades next to each other as it is realized in the most modern razors. The Inventive principle which clearly bridges this problem and this particular solution is Segmentation:

- Divide an object into independent parts.
- Make an object easy to disassemble.
- Increase the degree of fragmentation or segmentation.

This Principle seems to be a good abstract description of the solution. We have taken one razor blade and separated it in pieces thus creating a multi-blade razor (the control solution). Top-down approach in a design sense.

However, and this is a very remarkable observation, the NN-proposed Principle also nicely fitting this logic. Merging:

- Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.
- Make operations contiguous or parallel; bring them together in time.

We take a razor blade, “copy-paste” it placing the blades next to each other and we have a new engineering system. Down-top approach.

In other words, these two principles are in fact the opposite copies of each other and are leading in the end to the same solution. It means this incorrect answer given by the NN is not that incorrect. It “simply” generated it from the opposite side. We would like to illustrate this result with Fig. 2.



Fig. 2. Glass half full/Glass half empty. Segmentation/Merging.

#### 4.2. *Nesting doll vs. Merging*

For the Nesting doll control solution we used the following crowdsourcing problem formulation “The spyglasses that we have been producing are very popular on the market. We see that one of the new trends on the market is proposing larger and larger spyglasses with bigger zoom. The problem is the spyglass becomes too large for handling and transportation. Can you propose another high zoom spyglass design which would be easier to operate, transport and store?”

Of course the control solution is having a telescoping design which is a quintessence of the Nesting doll principle. However the NN proposed Merging again.

In fact Nesting doll is dealing with similar objects combined in the same system on an ever-receding scale and this is exactly what Merging is about: “Bring closer together (or merge) identi-

cal or similar objects”. No surprise the NN was not able to differentiate them and what is interesting is that the NN again has selected a variant which is so logically-close to the desired one.

## 5. Conclusions

Out of 6 problems, one has been classified correctly, two – conditionally correctly and three incorrectly (only one out of them is an outrage mistake). It gives us about 33% accuracy. We used a term “about” because it is not really clear how to estimate the results in this situation.

The authors are sure that the final accuracy could have been much higher if we could have used a larger learning dataset. For similar applications the datasets should be dozens of times richer. The larger datasets learning is one of the next steps we would like to research. Also larger amount of Inventive principles will be analyzed as well as having more than one Inventive principle per problem option.

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**Communicating Author:** [alexruin@mail.ru](mailto:alexruin@mail.ru)

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**STUDY OF EVOLUTION PATTERNS OF DISPLAY AND TSP TECHNOLOGY**

Minuk Kim<sup>a\*1</sup>, Harksang Kim<sup>a</sup>, Mijeong Song<sup>b</sup>, Kunwoo Baek<sup>b</sup>, Chang-Ryong Heo<sup>a</sup>, Kyuhyun Cho<sup>c</sup>,  
Hyeongsuk Yeo<sup>b</sup>

<sup>a</sup> *Telecommunication Business Division, Samsung Electronics, Suwon, South Korea*

<sup>b</sup> *Global Technology Center, Samsung Electronics, Suwon, South Korea*

<sup>c</sup> *Medical Device Division, Samsung Electronics, Seoul, South Korea*

**Abstract**

The article describes applying of TRIZ technology evolution patterns for prediction of new concepts in rapidly evolving DISPLAY and TSP (Touch Screen Panel) field. Evolution Mapping System (EMS) was utilized for this activity. EMS is special human-computer interface that helps to TRIZ specialist to analyse and classify massive numbers of related patents. Core part of this system is Technology Evolution Opportunity Map (TEOM). This map is visualizing multidimensional evolutionary analysis of existing patents and possible future patents. The process of the analysis and generation of ideas for next evolutionary steps is called by authors "Advance Invention Process"

The authors proposed following steps for Advance Invention Process:

1. Description of principle model of the delivering useful function by existing technology based on analyzed patent information.
2. Classification of the patent information using Evolution Mapping System (EMC) with building of macroscopic evolutionary map. This step involving estimation of the stage of evolution based on past technology evolution patterns (In this article, this step was described based on evolutionary patterns of DISPLAY and TSP (Touch Screen Panel) parts).
3. Prediction of near future, utilizing rules of "Transition to higher-hierarchical system" (In this article we demonstrate this step based on Smart Phone system. For this, estimation and classification of corresponding technological patterns was repeated for Smart Phone, based on evolutionary patterns utilized in analysis of DISPLAY and TSP (Touch Screen Panel).

Keywords: evolution map system; technology evolution opportunity matrix; technology evolution; in advance invention; technological evolution patterns

**1. Introduction**

*1.1. Motivation*

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<sup>1</sup> correspondence should be addressed to muk.kim@samsung.com

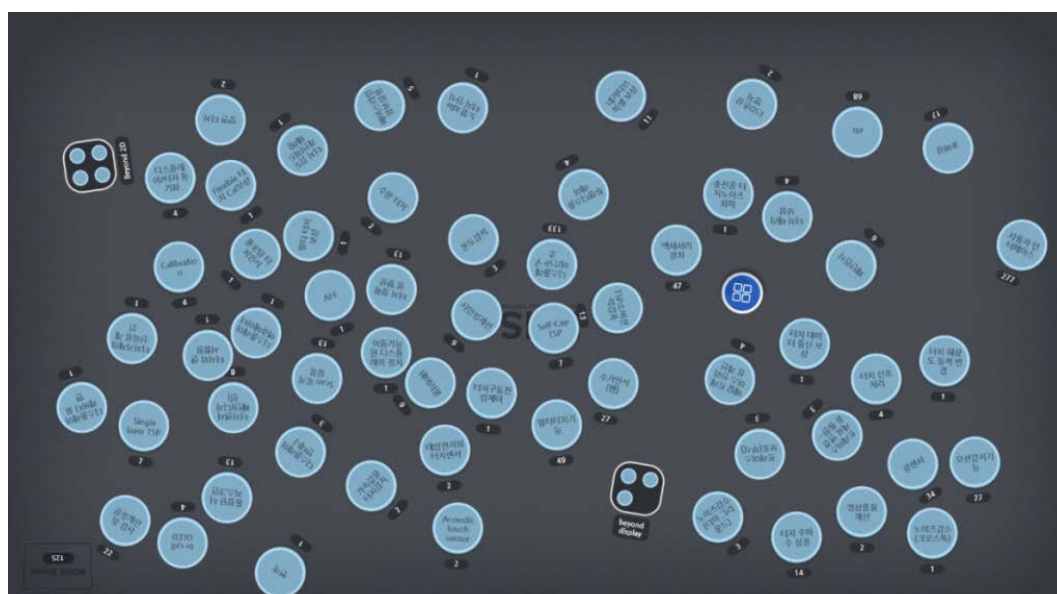
With the recent rapid evolution of smartphone display technology, demand for flexible displays and touch screen panels (TSP) is expected to expand and manufacturing markets are expected to grow sharply as production lines are expanded and equipment is replaced. Therefore, this study will be helpful for discovering DISPLAY and TSP (Touch Screen Panel) technology evolution patterns and for predicting future technology. We grew up listening to the words "the past is a mirror of the future" from history textbooks and reading article "If you want to know the future, first look at the past" written by Albert Einstein. I am confident that considering "looking at the past as a mirror", one can develop intelligent methodology to predict and prepare for the future.

## 1.2. Scope and Objective

We can read systems that are likely to appear in the future through the history of technological evolution, as it described in the article, "If you want to know the future, look at the past." In order to accelerating this process, one can utilize a series of patterns called 'technological evolutionary patterns'. There are eight laws of evolution proposed by Genrich Altshuler [2], later, researchers have developed these patterns of technological evolution in more details [3]. Samsung Electronics had selected 30 technology evolution patterns appropriate for the current situation and utilizes them from 2008. [4]. Applying the laws/patterns of evolution for interpretation of technical systems performing a specific function, a very diverse system can be pictured as a tree-system in biological evolution [5]. In addition to the tree structure, a multi-dimensional evolutionary analysis can be used to draw a matrix of evolutionary maps (TEOM) [6], giving a meaningful inspiration to the past, present and future direction of the system. In this paper, we propose an evolution map system (EMS) with a human-computer interface, which helps us to create a technology evolution map by analyzing patent information in order to know the technical characteristics of the near future. In order to propose a future patent concept and to support patenting and commercialization, we propose an IAI (In Advance Invention) process [1]. In this process, TEOM Light, a technique that helps to find detailed technical blank concepts, was developed and utilized in-house. By doing this, one will be able to obtain a multiple concepts for discovering and patenting practical new technology by performing certain functions.

## 2. Results and Discussion

This study utilized a new patent analysis interface called EMS (Evolution Map System) [1]. This analytical tool provides visualization interface with intuitive classification and opportunity to save data through real-time classification. Additionally, patent themes were classified by Binder classification by stored technology type [Fig.1].




<p>[Patent theme classification]</p> <ol style="list-style-type: none"> <li>1. Acoustic touch sensor 2건</li> <li>2. AFE 1건</li> <li>3. Calibration 4건</li> <li>4. Prevent ESD damage 2건</li> <li>5. Flexible display 10건</li> <li>6. Cal compensation of flexible touch 1건</li> <li>7. Force sensor 33건</li> <li>8. In-cell OLED 4건</li> <li>9. Scan logic settings 13건</li> <li>10. Self-Cap TSP 7건</li> <li>11. Single layer TSP 7건</li> <li>12. TSP power consumption reduction 13건</li> <li>13. Acceleration value touch detection 2건</li> <li>14. Surface (3D) screen 6건</li> <li>15. Process improvement and inspection 22건</li> <li>16. Light sensor 34건</li> <li>17. Negative pixel compensation 11건</li> <li>18. Narrow bezel 7건</li> <li>19. Normal Idle Touch Recognition 1건</li> <li>20. Noise reduction (dummy ground) 3건</li> <li>21. Noise reduction (crosstalk) 1건</li> <li>22. Display antenna 3건</li> <li>23. Display actuator 1건</li> <li>24. Display Cavity Surface 1건</li> <li>25. 디스플레이/TSP 구조 133건</li> </ol>	<ol style="list-style-type: none"> <li>26. Display / Touch Sync 4건</li> <li>27. Multi-touch compensation 1건</li> <li>28. Multi-touch function 49건</li> <li>30. Improved metal trace reliability 4건</li> <li>31. Motion detection function 27건</li> <li>32. Translation 1건</li> <li>33. Set baseline information 5건</li> <li>34. User interface 277건</li> <li>35. Biometrics 16건</li> <li>36. Handwriting recognition (pen) 27건</li> <li>37. Moisture touch 2건</li> <li>38. Improve visibility 9건</li> <li>39. Accessory device 47건</li> <li>40. Double-sided touch 2건</li> <li>41. Touch sensor of edge 9건</li> <li>42. Improve image quality 2건</li> <li>43. Temperature sensing 3건</li> <li>44. Wearable 9건</li> <li>45. Movable display device 1건</li> <li>46. Tactile feedback 22건</li> <li>47. Avoid touch noise during charging 1건</li> <li>48. Solar cell and touch sensor 2건</li> <li>49. Improved touch sensitivity (hardware) 1건</li> <li>50. Touch data communication compensation 1건</li> <li>51. Touch signal processing 4건</li> <li>52. Touch error compensation 4건</li> <li>53. Improved touch accuracy 13건</li> </ol>	<ol style="list-style-type: none"> <li>54. Touch frequency setting 14건</li> <li>55. Dynamic touch resolution 1건</li> <li>56. Touch drive voltage control 1건</li> <li>57. Improve reliability of touch substrate 1건</li> <li>58. Touch Sensor Pattern 8건</li> <li>59. Utilize sensors other than touch 1건</li> <li>60. Integrated touch screen 13건</li> <li>61. Transparent display 4건</li> <li>62. Trace protection (corrosion) 3건</li> <li>63. Noise improvement through trace material change 3건</li> <li>64. Pattern recognition 6건</li> <li>65. Floating Touch Recognition 1건</li> <li>66. Hovering 17건</li> <li>67. etc. 69건</li> </ol> <p>→ Completed 1006 cases from 1119 cases (Noise 113 cases)</p>  <p>특허 1119건</p>
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Fig. 1. Binder classification by technology type using EMS (Evolution Map System) Tool

Authors of the article studied Smart-Phone Display and TSP (Touch Screen Panel) parts through the patent themed classification.

Clear definition of the patent information that was found by searching keywords related to Display and TSP parts, was accomplished through the classified binder. Based on the principle model studied in TRIZ, we have analyzed and found some hidden technology evolution patterns.

[Major topics]

1. The user communicates with the device.
2. Touch the emotion of the display. (TEOM review)
3. I get to know each other on my own.
4. Awaken the sensibility of touch.
5. Touch your emotions.
6. Touch your thoughts.
7. The means of communication is diversified. (Evolution map review)
8. Touch me quickly and easily.
9. I have everything in touch.
10. Emotional touch, awaken instinct.
11. I find it easy and fast.
12. We approach customers easily and conveniently. (TEOM review)

There were many types of research themes among investigated the prior art, but topics 2 and 12 out of 12 investigated were selected as follows to design the new principle model. First, we found 'Beyond 2D' principle model through the classified Flexible Display, Edge Display, TSP, Narrow Bezel, and Surface (3D) Screen binders. Secondly, we could find 'Beyond Display & TSP' principle model through classified force sensor, tactile feedback, and Biological recognition binder. This gives the customer two beneficial functions and two insights can be found through a single princi-

ple model. First, "The senses of the human body touch the emotions to the customer." Second, "Form factor finds the action that it is easy and convenient for the customer" [Fig.2].

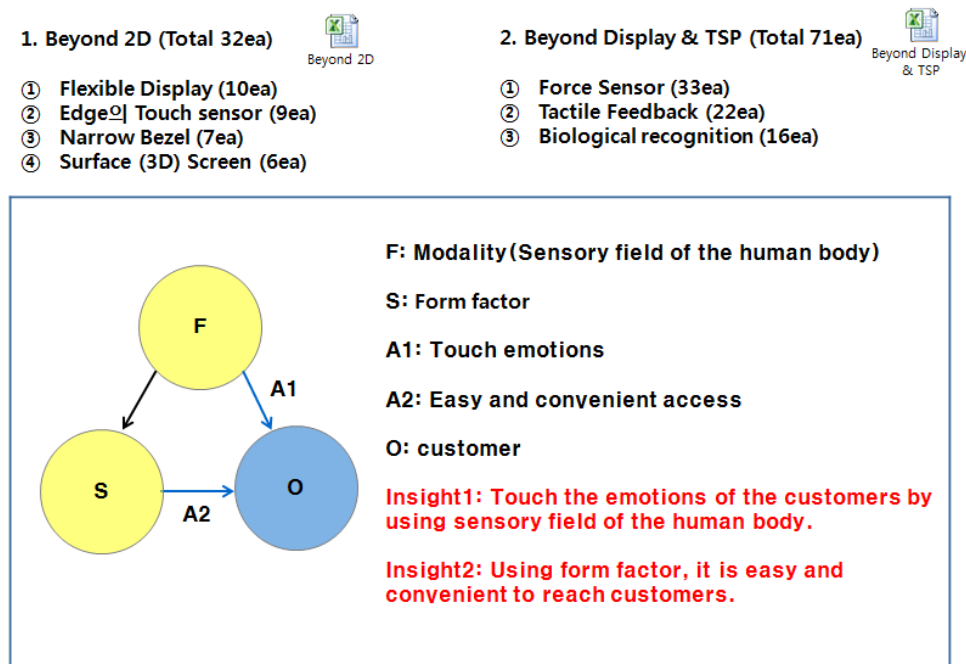


Fig. 2. Discovery of new principle model

Based on this new principle model, after a workshop based on analysis of selected patents, we could find the some technological evolution patterns of principle elements. The most similar behavior to the evolution / dynamics of the shape of the subject on the principle model was shown and for convenience the X axis was set. The field part on the technical principle model corresponds to the principle of the invention of the number / type of evolutionary patterns of information provided to a person, and is conveniently set on the Y axis. As a result of classifying the patent data with the X and Y axes set as above, we could draw TEOM (Technology Evolution Opportunity Matrix), which is a matrix-type evolution map as shown below. We have developed software called TEOM light that helps the process to improve the efficiency of analysis.

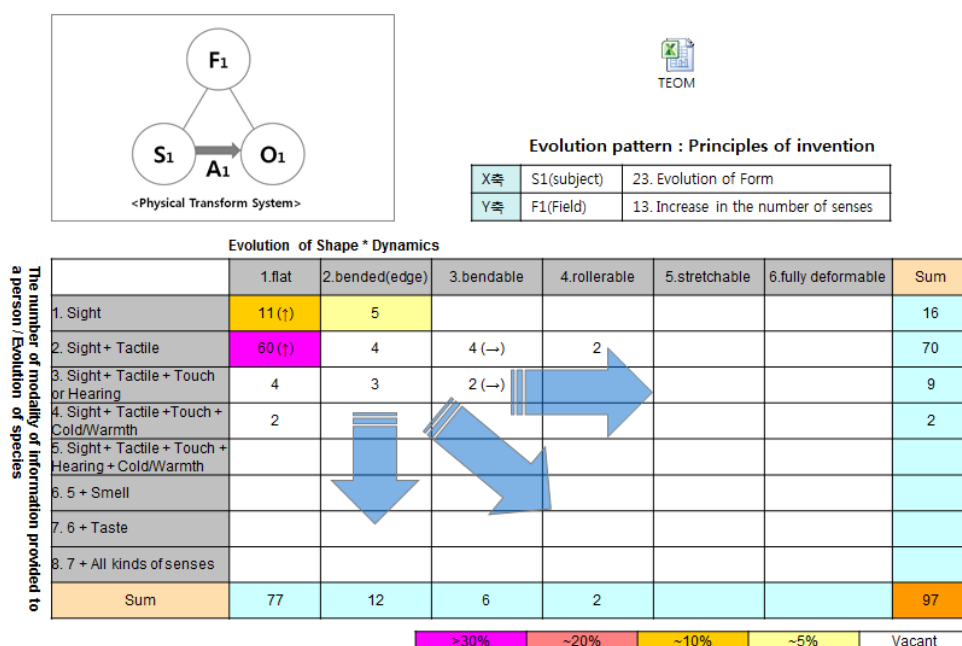


Fig. 3. TEOM of technology evolution pattern



Through the above process, we can see the evolution of TSP technology at a glance, and find the patents of the prior art and the blank spaces, where patents (“blank patents”) describing future steps can be easily proposed.

Before discovering a blank patent, researchers tried to answer the question: “is there a synthetic technical value of the evolution pattern of the DISPLAY and Touch Screen Panel shapes (X axis) and the number / kind of sense (Y axis) evolution pattern? “ The authors were able to find out the results of the research on the synthetic value through the five human senses. According to the results of the study, the influence of the five senses on the value matrix of synthesis was found to be greater for visual, auditory, tactile, olfactory senses. Therefore, it was necessary to draw the Evolution map from a macroscopic point of view to find out what kind of synthetic value it can bring to us by discovering the evolution of the five senses and the pattern of evolution of shape (dynamics).

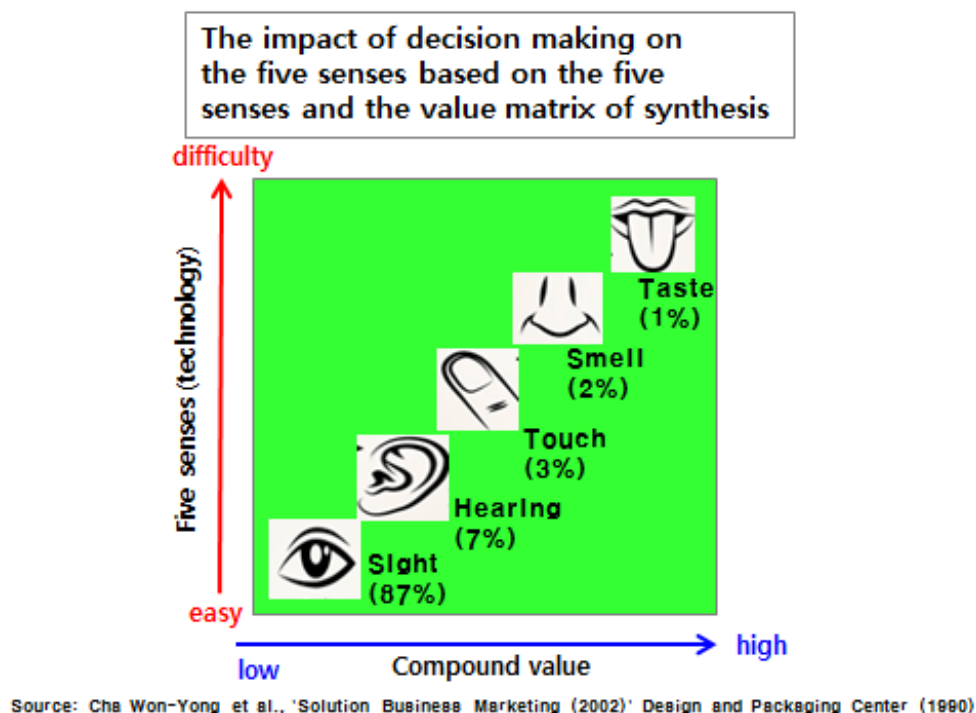


Fig. 4. The impact of decision making on the five senses based on the five senses and the value matrix of synthesis

The Evolution map is based on the prior art of the prior art (No. 2, No. 12, and No. 7), and we have found the direction of the evolution / dynamics of the shape. With a total of 1,119 registered and open patents, the macroscopic technological evolutionary pattern could be drawn to a large trunk (evolution of shape \* dynamics). I could find traces of the technological evolutionary pattern in the middle as a value stroke in the midst of the big stem of the technology evolution pattern. The Evolution driver was able to complete an Evolution map called 'Increase transformability'.



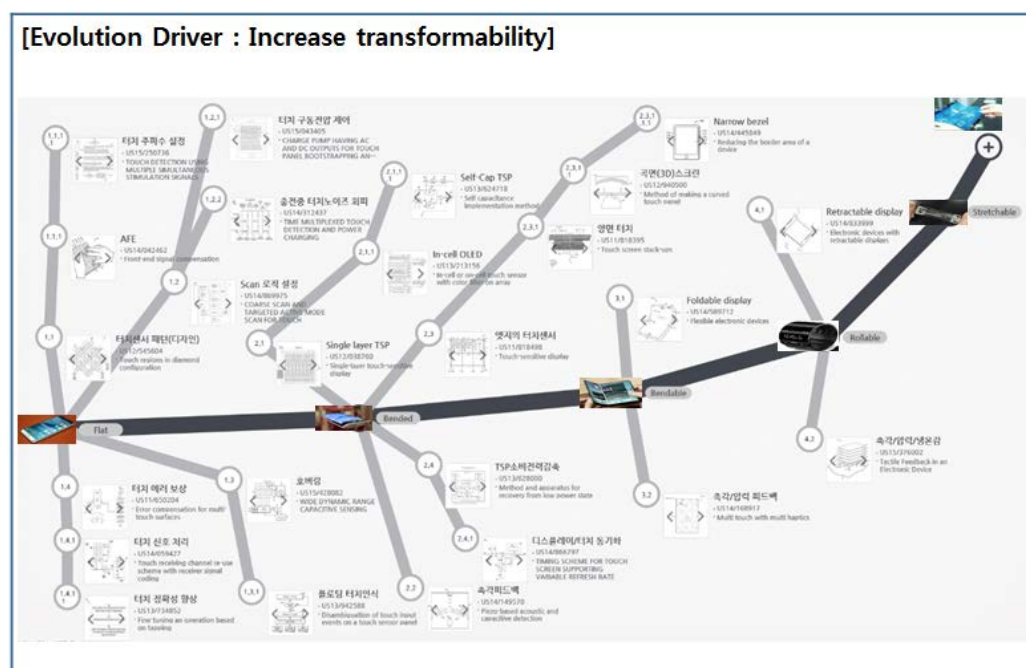


Fig. 5. Technology evolution map of the DISPLAY & TSP

However, at the present time, it was questions, which of the eight basic TRIZ patterns are applicable to technology system, and what is the next step, according to completed Evolution map.

[8 technological evolutionary laws/patterns]

#### A. System formation (static change)

- (1) System of completeness (Law of completeness)
- (2) Law of shortening of energy flow path
- (3) Law of harmonization of rhythms

#### B. Evolution of the system (movement)

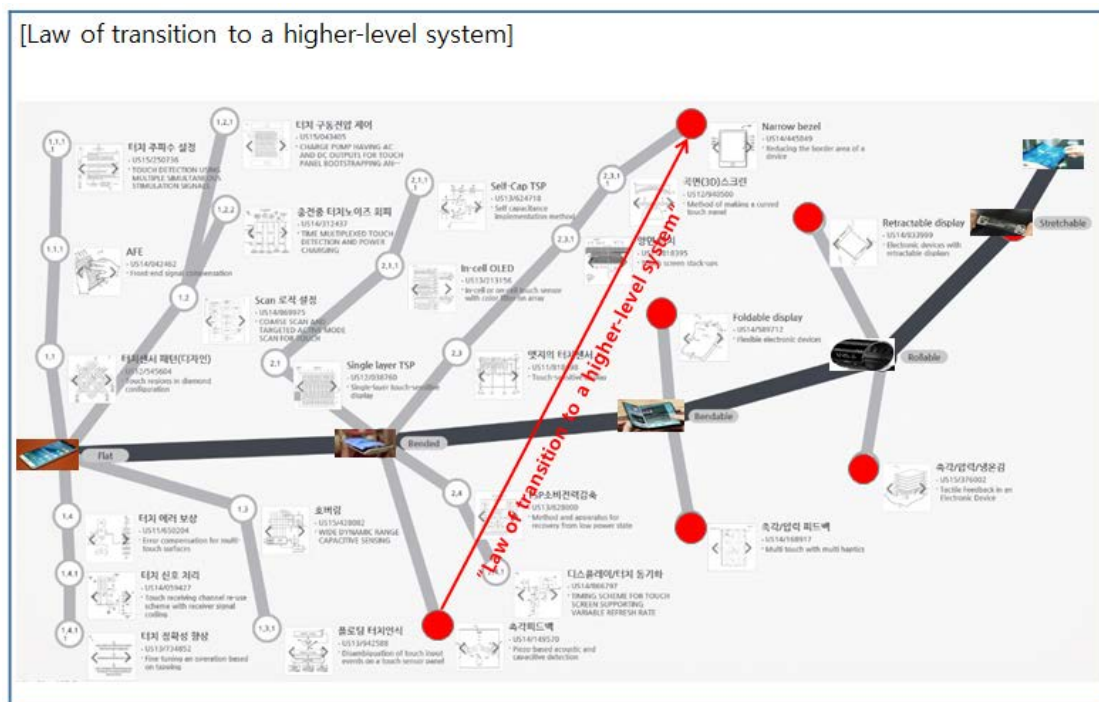
- (4) Law of increasing of ideality
- (5) Law of non-uniform evolution of sub-systems
- (6) Law of transition to a higher-level system

#### C. Increased dynamics (dynamics change)

- (7) Law of transition to micro-level.
- (8) Law of increasing dynamisms

Through the eight technological evolutionary laws, we found that Display and TSP are influenced by non-uniform development of each part on this stage of system. The reason for this is that when we look at the recent smartphone products through this Evolution map, we can confirm that Narrow bezel technology which is close to Zero bezel for display big screen from the viewpoint of design and structure is the upper system step that is almost reached the limit. On the other hand, the pressure sensor, tactile sensor, and biometric / fingerprint sensor were found to be immature by this Evolution map. It is confirmed by analysis of evolution map based on prior art that this step can improve various contradictions. As a result must Display, TSP, and each sensor are developing unevenly. This can be explained by eight technological evolutionary laws. As parts became more complex, the parts developed more unevenly. Thus, the uneven development of parts caused technical and physical contradictions, which caused technical problems. The next step is to predict the six laws of transfer and transition to higher systems.

The six laws of system uptake include the system as part of the higher system if the system exhausts all of its potential for development. By doing so, continuous evolution occurs in the parent system. It can be considered that the touch key area of the front lower side groove is exhausted and included as transition and part to the front surface of the display or the narrow bezel area and the edge device for the Smart-Mobile Display large screen. In other words, the macroscopic Evolution map was able to detect the current state of the art and contradictions in the immediate situation. In this way, we have been able to discover the evolutionary patterns of technological evolutionary laws and predict the evolution of the law of non-uniform evolution of sub-systems to a higher-level system. Therefore, if it is difficult to implement the front sensor on the Narrow bezel for large-screen display, the Narrow bezel area becomes almost zero, and I was able to generate idea of the structure including the biometric / fingerprint sensor, the tactile sensor and the pressure sensor on the edge or side structure. As the development of large screen display, the home key and fingerprint sensor in the lower front area of the display were exhausted, and the edge or side structure became a part of the upper system, and it was predicted that continuous power generation would occur in the upper system. Through these predictions, we were able to specify the idea (patent pending stage) along with the detailed specification for the patent application. Evolution map enables us to discover new technologies in the past, present and the future. The evolutionary laws of this technology will go beyond the six laws to the Law of transition to micro-level (Law 7) and Law of increasing dynamisms) were utilized to predict the future evolutionary steps.



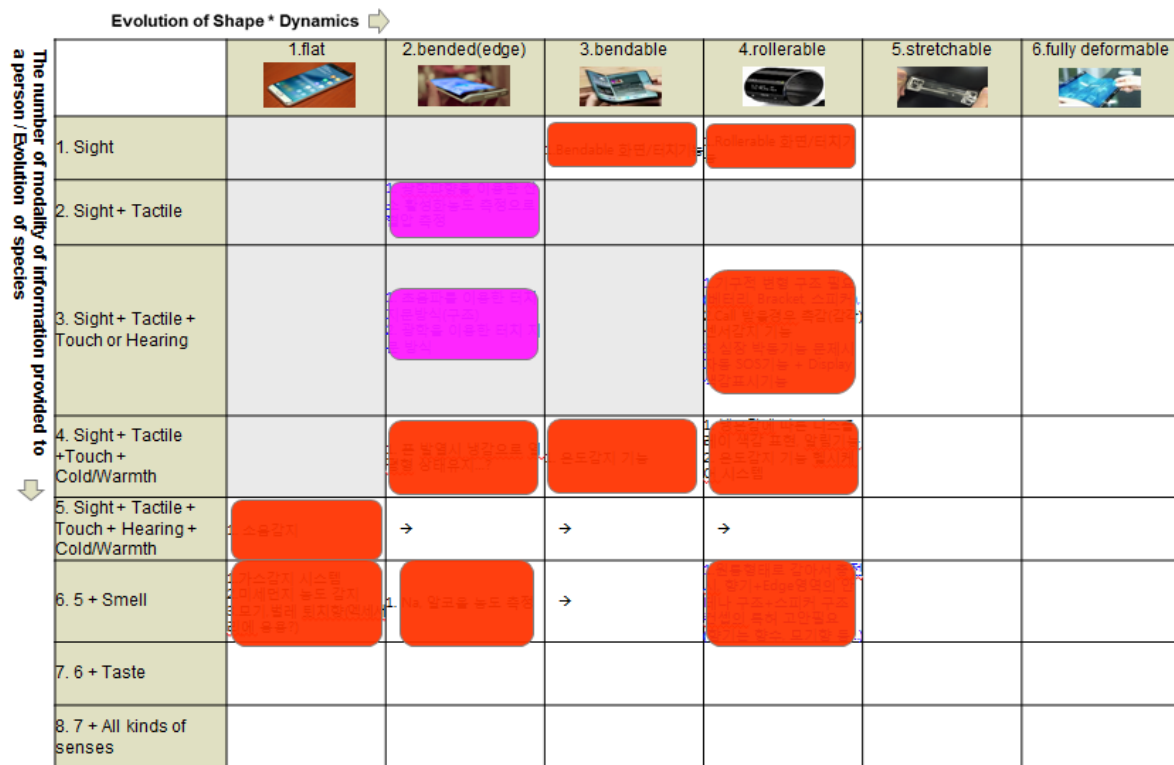


Fig. 7. Proposal of idea through the synthesis value of the evolution of the five senses and the evolution of the form (dynamics)

Table 1

Almost all sensors respond to one of human senses

Sense	What to detect
Sight	Brightness, presence of human or object, image(Stop, motion, special information such as facial expressions)
Touch	Position, force, pressure, silpperiness, temperature, shape, contour(person or object), flow rate and flux
Hearing	Acoustic, low frequency vibration, ultrasonic, acceleration, gravity
Smell	Incense, smell, various gases
Taste	Ingredietnts offood

### 3. Conclusions

This study focuses on predicting and preparing for market changes by analysing the technological evolution patterns of the DISPLAY and TSP field in which the authors are involved. By examining and classifying the patent information of the prior art and applying the principle of invention of the technology evolution pattern using the TRIZ principle model, we confirmed that the patent of TEOM and promising domains of the new technology can be discovered in the future. Through the EMS tool, we made precise and intuitive Binder classifications of the prior art, which enabled us to draw a macroscopic Evolution map. By applying the "law of system non-uniform development" we estimated the present stage of technological evolution through the completed Evolution map and applied the technological evolutionary rules for establishment of product strategy.

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**Communicating Author:** muk.kim@samsung.com

## **TRIZfest 2018**

**September 13-15, 2018. Lisbon, Portugal**

### **TRIZ&TOC TOOL INNOVATION: VIBRATION SENSORY (VS) LANGUAGE FOR DEAF**

José Roberto Espinoza Villarroel

General Manager

*Open TRIZ Second Wave Chile SpA, Viña del Mar, Postcode 2520168, Chile*

#### **Abstract**

The objective of this paper is to show an innovation development for deaf language of global impact, based on current technologies and that has been achieved by applying the methodology proposed by the systematic innovation tool TRIZ & TOC TOOL, presented in TRIZFest-2017. This has allowed us to obtain a solution using a portable device that allows deaf people to perceive words through pulses of vibrations.

Solution is in prototype phase and was presented to the challenge INNOCENTIVE: SIGN FOR LITERACY, Deadline: February 16, 2018 23:59 EST. The Foundation "All Children Reading" informed on 11.07.2018 that proposal was not a finalist, since evaluations focused on improving local access to sign language and instead I proposed a new way of communicating.

This article shows methodology applied in different phases until the presented solution is achieved.

Below are the main aspects to include in the paper:

#### a) Formulation of the problem

The development of the conceptual solution required the application of TRIZ & TOC TOOL (T&T) with its AATRIZINVENTOR algorithm, for the following aspects that emerged during the analysis of the proposed challenge:

##### - Current Situation

T & T Current sign language for the deaf. Evaluated Object: Sign Language for the Deaf.

T & T Current sign language for the deaf. Evaluated Object: Deaf People.

##### - Technology Research

Technological research on advances and innovations in communication with deaf people.

Scientific research on deafness studies, human listening mechanism and limitations.

##### - First solution approach

T & T Sound vibration language for the deaf. Evaluated Object: Sound Vibration Language for the Deaf.

##### - Final Solution Analysis

T & T Vibration sensory language for the deaf. Evaluated Object: Vibration Sensory Language for the Deaf.

T & T Vibration sensory language for the deaf. Evaluated Object: Deaf People.

##### - Formulation of Conceptual Solution

Definition of portable device characteristics that allow deaf people to perceive words through vibrations.

Research of low-cost technical equipment to design prototype conceptual solution achieved.

#### b)

Three low-cost prototypes with different technologies and one for teaching and training by PC are in the commissioning phase.

c) Expected Benefits for the Vibration Sensory Language for the Deaf

The innovation provides a novel, yet robust approach for language resources for the deaf as a path to literacy. To facilitate early language acquisition, the innovation allows the development of learning resources, while promoting access to this newly-developed resources. Test Prototype

The innovation is usable by children who are Deaf, requiring only the collaboration in their own language of their relatives, educators and / or other members of the community who interact with children for learning.

Innovation is an innovation based on technology and considers:

- low-cost and affordable for uptake
- ☐ Function fully in low resource settings, specifically addressing:
  - o Limited or intermittent electricity
  - o Limited or intermittent internet access
  - o Limited personnel for software/hardware support
  - o Adaptable to multilingual countries with multiple written and/or sign languages

For the deaf is expected:

- o Rapid learning, studies in the deaf indicate that they have superior skills to feel and interpret vibrations.
- o The use of language can begin in the first months of life. It is a sensory method.
- o Facilitates the possibility of learning to speak, through self-feedback: "he listens to himself".
- o Facilitates the management of time: present, past, future.
- o It facilitates the learning of reading and writing a language.

The VS LANGUAGE FOR THE DEAF does not store the spoken messages that are transformed and transmitted as vibrations. The message is kept only the time it takes to transmit. Nothing can stop the transmission: if you do not understand, you ask to repeat.

We must respect the necessary privacy that every human being requires.

## **1. BRIEF REVIEW OF TRIZ&TOC TOOL - UPDATE 2018**

TRIZ & TOC TOOL is a tool for accelerated systematic innovation to solve people's problems, which follows the line of abductive thinking, based on the hypothesis of formulating problems using the TOC Evaporation Cloud and the solution of problems based on the Matrix of Contradictions of TRIZ. Demonstration of hypothesis is empirical.

TROZ&TOC TOOL is based on the following pillars:

### **1.1 Social and human context of needs to be solved**

It is postulated that a problem exists if it directly or indirectly affects people.

People live in a social and human context, where their unmet needs are manifested, which are represented as the problem.

There are unmet needs that people declare impossible to solve, then they see limited possibility to change the current state.

When an unmet need is analyzed it is possible to discover different causes, that is, the problem is multivariable: for example: it is slow, it has no strength, it is heavy, etc.

TRIZ & TOC TOOL proposes a methodology to solve a multivariable problem with accelerated systematic innovation.

### **1.2 Own knowledge of the business involved and the technologies available in the world.**

To solve a problem, we consider it essential to know why it occurs, where it originates, what parts are involved, that is, to feel the problem. Innovation is change and change exists if compared to a reference where the problem is to be solved.

Innovation integrates technologies and existing methods in a permanent evolutionary process, solving problems that we even believe impossible to solve.

Scientific discoveries and technological breaks generate innovation in latent or potential problems for the current state of development.

1.3 Formulation of the multivariate problem using modified Evaporation Cloud of Theory of Constraints (TOC).

To solve a multivariable innovation problem, its formulation is key. It is necessary to initially represent the problem through a substance-field analysis, which relates two properly identified Objects, interacting through a defined field and from there selecting the Object on which the problem will be formulated. It is necessary to emphasize the importance of accurately identifying the Object to be evaluated, since the TRIZ engineering parameters that are applied to a multivariable innovation problem must be related to a unique Object. See point 2. Object must be understood in the broadest sense in which human needs are manifested and beyond.

Modified Evaporation Cloud of Theory of Constraints (TOC) [1] allows a logical formulation of a multivariable problem by means of a diagram that we have called "RCA + EC" [2], relating in this diagram harmful causes and desired useful causes. Causes can be independent or dependent, they must all be declared. The solution will commonly surprise us. The method of innovation of Morphological Analysis is a useful tool also to conceptualize the formulation of problems as explained in [3].

TRIZ & TOC TOOL postulates that, for a set of causes, useful and harmful, there is an essential contradiction that leads the solution of the problem, being able to be between any two identified causes and whose detection allows to accelerate the search for a multivariable problem solution.

1.4 Search solution to multiple contradictions applying TRIZ's Matrix of Contradictions, Theory of Inventive Problems Solving (TRIZ).

Having formulated the multivariable problem, the next challenge is to identify TRIZ engineering parameters that are deduced from the "RCA + EC" diagram. Most parameters can be easily related to identified causes, however, our practical experience found in some cases difficulties to relate identified causes with appropriate parameters. A more analytical look at the TRIZ engineering parameters tells us that defined parameters are sufficient and only a more universal description based on relational thinking is required. In point 1.6 a first more universal definition of some TRIZ engineering parameters is given, whose greater explanation will be delivered in future book in writing.

Application of TRIZ engineering parameters with universal description allowed to establish hypotheses that Matrix of Contradictions is a tool that allows to find innovation solutions in any field of human development and beyond.

TRIZ & TOC TOOL establishes as criteria to identify in a multivariable problem up to 4 harmful factors and 1 useful factor. TRIZ engineering parameters are divided into 30 parameters that can be harmful for a given objective and 10 parameters that can be useful for the same given objective,

described later. Parameter adaptability or versatility applies in both cases, it is harmful when adaptability of the evaluated object is affected by external variable factors and is useful when we want to improve the variability of the object evaluated. Based on morphological analysis, it is established that each useful parameter represents a sub-problem with its own solution, the general solution being an integration of these sub-solutions, which should also consider the inventive principles that solve contradictions that occur between those 10 useful parameters.

Established engineering parameters that apply to solve the multivariable problem, it is possible to generate a sub-matrix of contradictions, where TRIZ & TOC TOOL hypothesis is that sub-matrix contains a real solution to the formulated problem.

The sub-matrix referred to above, with up to 5 TRIZ engineering parameters, can contain up to 20 contradictions with their respective inventive principles, then to build the general solution of the problem we do not know where to start, work becomes tedious and difficult to orientate. Worse yet, if we want to sensitize a parameter, either eliminating it or replacing it with another, we must repeat analyzes again. Manual intellectual work in a digital world is not justified.

This is how it is born AATRIZINVENTOR.

#### 1.5 Mathematical algorithm of fast approach to the solution [www.aatrizinventor.com](http://www.aatrizinventor.com).

AATRIZINVENTOR is a mathematical algorithm based on the following criteria, which apply to the sub-matrix of contradictions where the solution to the formulated problem is found:

- a) It is defined for each contradiction, the weight of an inventive principle according to the position it occupies. The highest value is assigned to the first place and thus with descending values successively up to fourth value. This value is unique for each position and applies to all sub-matrix contradictions.
- b) The global weight of an inventive principle is determined from sub-matrix, as a function of weights obtained in each of the contradictions where it appears. The global weight is calculated for all inventive principles that belong to sub-matrix.
- c) WT weight of a contradiction is determined as a function of the global weight of each inventive principle that participates in it.
- d) Contradiction that obtains greater value WT corresponds to essential contradiction that is postulated makes greater contribution to solution. then, in descending order, the importance of contradictions varies.

ATRIZINVENTOR is a mathematical calculation that prioritizes contradictions and inventive principles that participate in sub-matrix, delivering an initial proposal of analysis to formulate the solution. In practice, this assumption has been very effective.

#### 1.6 Universal Engineering Parameters & inventive Principles

TRIZ engineering parameters and inventive principles are a technical expression of human needs, since this parameters and principles have been deduced precisely from that technical field, evaluating a huge number of cases, more than 2.000.000 today. As a corollary, is possible affirm that TRIZ engineering parameters and inventive principles correspond to an exhaustive sampling of human needs and therefore are statistically representative for all human actions that occur in this world. Their current writing only reflects the technical source from which they were established.



This explains common practice of "translating" TRIZ parameters and principles to different areas of knowledge.

The experience of application of TRIZ & TOC TOOL in various areas of human development, recommends us to give a more universal wording to some parameters of engineering and inventive principles, which allow their more direct application.

#### 1.6.1 Engineering parameters

Engineering parameters that have been considered convenient to give a more universal definition are:

Par.01.- Heaviness of moving object / 02.- Heaviness of stationary object

Heaviness in the property or characteristic acquired by an object due to an external field that affects it.

- Weight of an object is effect of the gravity field
- Cost of an object is effect of the economic value field

Par.17.- Temperature or level of internal activity of an object

It adds a level of internal activity that manifests externally, reflecting energy.

- Temperature is a reflection of thermal energy.
- Motivation is a reflection of personal attitude (internal energy).

Par.18.- Emission intensity of an object

Emission intensity is a measure of which one object becomes sensitive to another

- Intensity of illumination is a measure of the light emitted by an object
- Intensity of radiation is a measure of the energy emitted by an object
- Visibility is a measure of the detectability of an object

Par 32.- Easy of manufacture / of achieved goal

This parameter represents the ability to meet the objective, e.g., to manufacture something.

Par.34.- Easy to change, repair, maintain or avoid

This parameter represents the ability of an object to change, whether by change of status or condition, by repair, by maintenance or by avoiding changing to an unwanted state or condition. It is key to innovate.

#### 1.6.2. Inventive principles

Inventive principles that have been considered convenient to give a universal definition are:

IP.29.- Controllable soft variables - Pneumatics, Hydraulics, Electrical & Digital

Controllable soft variables are those that allow fast, effective and flexible operation and control actions. Currently, digital variables play a relevant role.

IP.30.- Flexible shells and thin films/Simple physical forms/Simple ways

This inventive principle can be summarized as solution application simplicity to human scale.

IP.31.- Take advantage of useless parts/Porous materials

- Use porous materials to reduce weight supporting structures
- To give stability to an object eliminate useless parts that affect it

IP.32.- Perception/Appearance/Colour changes

- To improve the visibility of an object, change its color
- To improve the exposure of an object, decorate it
- To improve the interaction of one object with another, modify it

37.- Sensitive change of an object due to applied field

- Use expansion of an object, due to application of heat, to interact with another.
- Use vibration of an object, due to electromagnetic field application, to interact with another.
- Use person motivation, due to incentive, to interact with another.

38.- Strong & rapid reactions

- Use strong oxidants
- Use high voltage pulses
- Use aggressive offers

Finally, according to our experience it is necessary to keep in mind that inventive principles are written for a certain condition, but each specific problem will recommend its application directly or in reverse.

For example, in a real problem of locking in transport of copper sheets on idlers, recommended solution included segmentation. The solution applied was to eliminate the existing segmentation, moving to a continuous conveyor belt.

## **2. PROBLEM FORMULATION USING TRIZ TOC TOOL – UPDATE 2018**

### **2.1 Objects and Fields in TRIZ & TOC TOOL**

To learn about TRIZ, we can usually find examples of problems formulated from two engineering parameters, which are in contradiction. Solution is simple and consistent and we fell in love with TRIZ. However, real problems are more complex, they are multivariable, that is, there are multiple contradictions.

TRIZ identifies its engineering parameters related to an Object, then in a multivariable problem, the possible causes must refer to this same Object. This logical statement simplifies formulation of a multivariable problem, since a single object does not generate many causes, does not have so many degrees of freedom, or in TRIZ language, few engineering parameters are involved, 3 to 7 according to our experience.

Then, to start solving multivariable problems, we must identify a single Object to which to relate the identified causes and then apply TRIZ. But this is not enough to formulate a problem that we want to solve, TRIZ teaches us that a problem can only appear when two objects, S1 and S2, interact as a system through the F field. Here we recognize another essential TRIZ tool for TRIZ and TOC TOOL, the substance / field analysis. As is known, substances are objects of any level of complexity, they can be individual elements or large systems, physical or intellectual matters. Field is the action or transfer of energy between two interacting Objects.

TRIZ & TOC TOOL formulates a multivariable problem based on two interacting objects, which must be formulated from the perspective of each of them, where each object has its own causes,

contradictory engineering parameters, which generate the problem. Final solution will be integration of proposed solutions for those two evaluated objects.

Concluding, first pass to solve problem is to identify objects S1 and S2.

This first selection of objects gives us an initial solution, which leads us to a new theoretical operation, which must be evaluated again analyzing expected contingencies, selecting objects associated with a new state or condition, to refine the initial solution and finally reach a definitive solution. This process can be applied sequentially as many times as necessary.

## 2.2 Diagram "RCA + EC" of Problem Formulation

Once two objects to be evaluated have been identified to solve the problem, it is recommended to generate Diagram "RCA + EC" of Problem Formulation, see Fig.1, which allows to express the mental map of the analyzed problem. This helps to validate or correct the logical analysis proposed, avoiding, for example, assigning causes of an object S1 to object S2. This recommendation may seem obvious, but if it is not considered, it distorts the solution that we believe we have obtained.

To explain how this diagram is constructed, Fig.1, we will first start with parameters associated with causes that we want to avoid. A TRIZ parameter is selected as harmful when it is possible to relate it to the cause, state or condition of the evaluated object that generates the problem. Table 1 shows parameters that we can select. Then Triz Eng. Par. 1, 2, 3 and 4 from Fig.1 must be selected from list of parameters indicated in Table.1

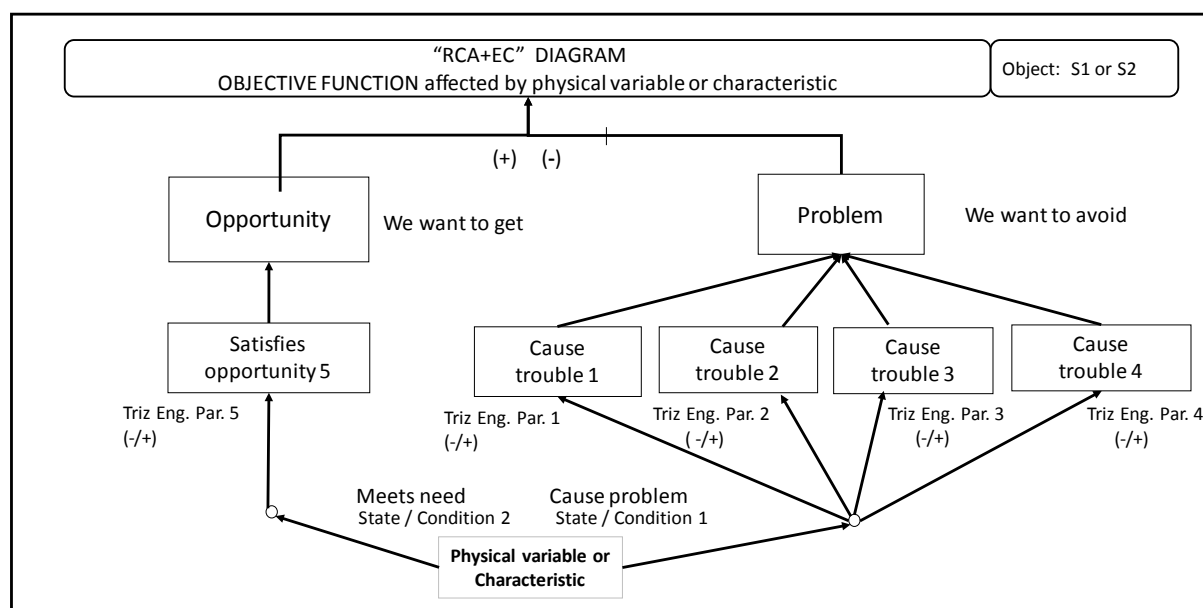


Fig. 1 "RCA+EC" Diagram

Table 1

Potential harmful engineering parameters TRIZ

01.- Heaviness of moving object	18.- Emission intensity of a object
02.- Heaviness of stationary object	21.- Power (energy per unit of time)
03.- Length of moving object	22.- Loss of Energy

04.- Length of stationary object	23.- Loss of substance
05.- Area of moving object	24.- Loss of Information
06.- Area of stationary object	25.- Loss of Time
07.- Volume of moving object	26.- Quantity of substance/the matter
08.- Volume of stationary object	28.- Measurement accuracy
09.- Speed	29.- Manufacturing/Composing precision
10.- Force (Intensity)	30.- Object-affected harmful factors
11.- Stress or pressure	31.- Object-generated harmful factors
12.- Shape	35.- Adaptability or versatility
14.- Strength	36.- Device complexity
17.- Temperature or level of internal activity of a object	37.- Difficulty of detecting and measuring

In relation to the opportunity we want to obtain, a TRIZ parameter is selected as useful when the desired cause of the problem refers to complete feature of the object, which directly satisfies the desired objective.

The practical application of TRIZ & TOC TOOL tells us that what we want to obtain can have the following objectives, expressed as TRIZ engineering parameters in Table 2.

Then Triz Eng. Par. 5 must be selected from list of parameters indicated in Table.2. It will usually be necessary to evaluate several of these parameters, one at a time with the set of harmful or unwanted parameters identified, to achieve the most effective solution. The recommended order is to start with left side parameters and then continue with right side. 16 or 20 and 15 or 19, one of them.

A parameter is included in the evaluation when its participation or incidence is recognized in the evaluated problem, no matter its relation of dependence or independence of other parameters also to be included.

Table 2

Potencial useful engineering parameters TRIZ

33.- Ease of operation	27.- Reliability
34.- Easy to change, repair,maintain or avoid.	38.- Extent of automation
32.- Ease of manufacturing / composing	35.- Adaptability or versatility
16.- Use of Energy moving object	13.- Stability
20.- Use of Energy stationary object	15.- Duration of the action moving object
39.- Productivity	19.- Duration of the action stationary object

### 2.3 Use of mathematical algorithm of fast approach to the solution

"RCA + EC" diagram allows obtaining a sub-matrix with the contradictions that are formed between all identified parameters. If the problem is well formulated, then the sub-matrix includes a solution to the evaluated problem, whose identification requires the revision of all the existing sub-matrix contradictions. The review indicated can be slow and confusing to formulate a solution, then

an algorithm has been developed, hosted at [www.aatrizinventor.com](http://www.aatrizinventor.com) , which allows for accelerated and assertive identification of the major contradictions which largely meet the problem.

Under an abductive analysis, it is postulated hypothesis to find out the essential contradictions that delivers maximum benefit with minimum changes, applying a mathematical algorithm that weighs the inventive principles of each pair of parameters of engineering TRIZ identified, based on the number of times it is repeated in the box of contradiction and according to their relative position in each specific contradiction in the box.

It has been defined to evaluate up to 5 engineering parameters, that is, to analyze up to five degrees of freedom of the problem, which for two specific objects that interact has been sufficient, according to practical experience we have had. Use of algorithm has presented great advantages to accelerate the search for solutions and perform sensitivity analysis of multivariable problem formulation, break paradigms, find solutions that our mental rigidity initially prevented to conceive.

### 3. TRIZ&TOC TOOL INNOVATION: VIBRATION SENSORY (VS) LANGUAGE FOR DEAF

#### 3.1. Initial Analysis Innovation Solution for Language for the Deaf

To initiate the process of solving the current sign language innovation problem for the deaf, we must postulate a substance / field diagram that represents action under evaluation:

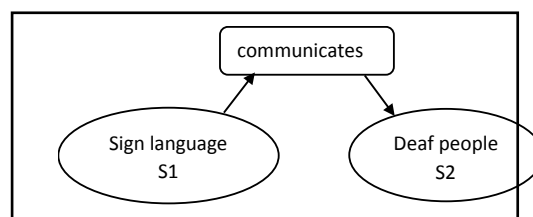


Fig.2 Substance/Field Analysis Current Sign Language for the Deaf

Next we will develop the analysis for each object S1 and S2. As you will appreciate, each object identifies its own causes.

The challenge is to find a solution that meets both evaluations.

##### 3.1.1 Current Sign Language for the Deaf / evaluation Object S1 Sign Language for the Deaf

Our first analysis will be to evaluate the current problems from the perspective of SIGN LANGUAGE FOR THE DEAF.

The analysis criterion will be to represent the main harmful and useful effects that it faces, to determine the existing contradictions.

The multivariable problem obtained from RCA+EC diagram, Fig.3, is evaluated with AATRIZINVENTOR and first solution recommendation is obtained.

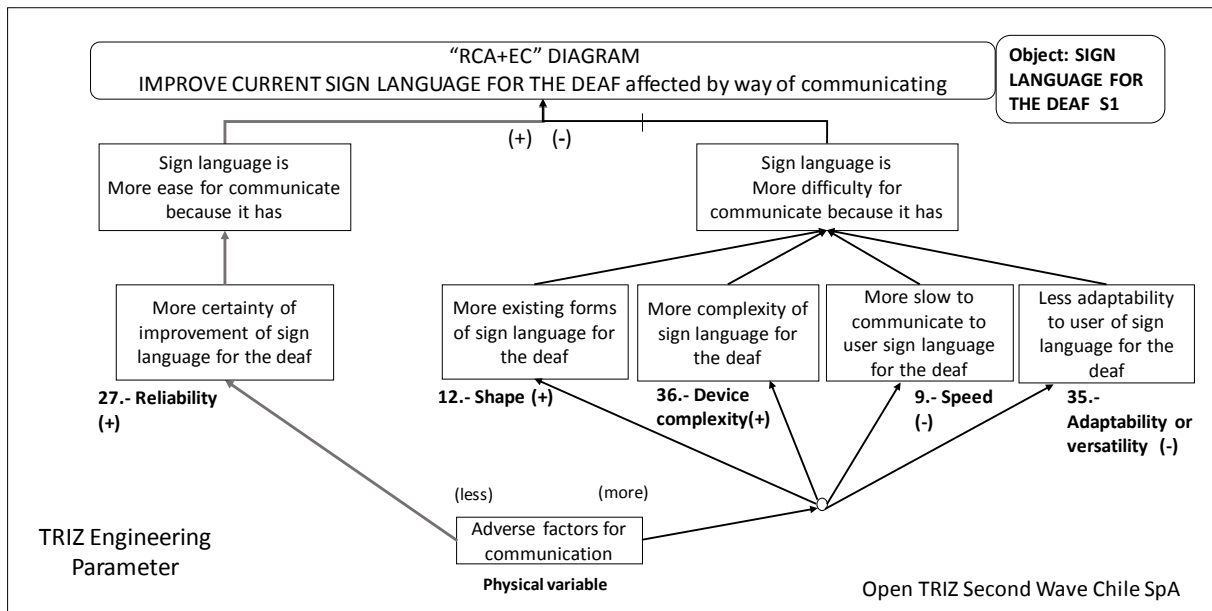


Fig. 3 "RCA+EC" Diagram Improve Current Sign Language Object S1 Sign Language

Diagram in Fig. 3 shows five TRIZ engineering parameters that will be evaluated and from these the contradictions submatrix and the recommended initial solution table are obtained. Table 3 shows the sub-matrix obtained that contains the following information:

Green color contradiction: Corresponds to the essential contradiction of problem (WT.1), that is, the one that has the greatest contribution to solution, determining relevant engineering parameters. The contribution of the following contradictions decreases in correlative order. Parameters (36,12).

Blue color contradiction: Corresponds to complementary contradictions to solve the problem, associated with relevant engineering parameters identified. (36,12).

Yellow color contradiction: Corresponds to the top 5 contradictions to solve the problem, not associated with the relevant engineering parameters. Parameters (27,36) and (12,35).

From the sub-matrix of contradictions, an essential contradiction is selected and four major complementary contradictions to form a solution table to obtain an initial solution to the problem, see Table 4.

Green color inventive principles correspond to those that are included in essential contradiction.

Blue color inventive principles correspond to those considered complementary.

Inventive principles white color correspond to those considered as optional.

According to the relevant inventive principles identified when evaluating the Object. Table 3 and 4: SIGN LANGUAGE FOR THE DEAF, the solution should guide and focus on:

- (IP 29) LANGUAGE FOR THE DEAF of the deaf must be controlled with soft variables such as electrical or digital
- (IP 13) It is necessary to use indirect LANGUAGE FOR THE DEAF
- (IP 28) Replace in LANGUAGE FOR THE DEAF mechanical means with a sensory means. Use electric, magnetic, and electromagnetic fields to interact with DEAF PEOPLE.

Table 3

Sub-matrix of Contradictions to Improve Current Sign Language. Object S1 Sign language

Par. Improve / Attenuate or preserve	Var.	12.- Shape	36.- Device/Action complexity	09.- Speed	35.- Adaptability or versatility	27.- Reliability	Sum%(Fij)
12.- Shape	Fij		WT.9	WT.8	WT.5	WT.17	58%
12	IPs.	0,0,0,0	16,29,1,28	35,15,34,18	1,15,29,0	10,40,16,0	
36.- Device/Action complexity	Fij	WT.1		WT.12	WT.10	WT.3	94%
36	IPs.	29,13,28,15	0,0,0,0	34,10,28,0	29,15,28,37	13,35,1,0	
09.- Speed	Fij	WT.7	WT.20		WT.16	WT.15	37%
9	IPs.	35,15,18,34	10,28,4,34	0,0,0,0	15,10,26,0	11,35,27,28	
35.- Adaptability or versatility	Fij	WT.13	WT.11	WT.14		WT.18	39%
35	IPs.	15,37,1,8	15,29,37,28	35,10,14,0	0,0,0,0	35,13,8,24	
27.- Reliability	Fij	WT.2	WT.4	WT.6	WT.18		80%
27	IPs.	35,1,16,11	13,35,1,0	21,35,11,28	13,35,8,24	0,0,0,0	
Sum%(Fij)		100%	62%	52%	48%	46%	

Table 4

Recommended Solution Table to Improve Current Sign Language. Object S1 Sign Language

Solution table	Essencial Contradiction	Supplementary Contradictions with Preferred Parameters (*)			
Eng. Par. to Improve	36.- Device/Action complexity	27.- Reliability	36.- Device/Action complexity	09.- Speed	36.- Device/Action complexity
Eng. Par. to Attenuate or Preserve	12.- Shape	12.- Shape	27.- Reliability	12.- Shape	35.- Adaptability or versatility
Weight priority	WT.1	WT.2	WT.3	WT.7	WT.10
IPs. Priority 1	29	35	13	35	29
IPs. Priority 2	13	1	35	15	15
IPs. Priority 3	28	16	1	18	28
IPs. Priority 4	15	11	0	34	37

- (IP 15) Deaf language characteristics must be designed to achieve optimal operating conditions.
- (IP 35) Change the composition or condition by adding components to language for the deaf.
- (IP 10) Perform, before it is needed, the required change of language for the deaf (either fully or partially)
- (IP 1) Divide language for the deaf into independent parts.
- (IP 16) Calibrate language for the deaf using a given solution method then, by using 'slightly less' or 'slightly more' of the same method, the problem may be considerably easier to solve.
- (IP 18) Cause to language for the deaf oscillate or vibrate.
- (IP 34) (IP 34) Make portions of language for the deaf that have fulfilled their functions go away.
- (IP 37) Use changes that occur by applying a field to language for the deaf useful for deaf people.

Particular conclusion: Language for the deaf must be activated by energy fields that make it vibrate and be sensitive to the deaf.

### 3.1.2 Current Sign Language for the Deaf / evaluation Object S1 Deaf People

RCA+EC diagram to be evaluated is shown in Fig.4.

Again, from selected parameters, sub-matrix of contradictions and solution table are generated, Table 5 y6, where the colors correspond to the same specifications described above.

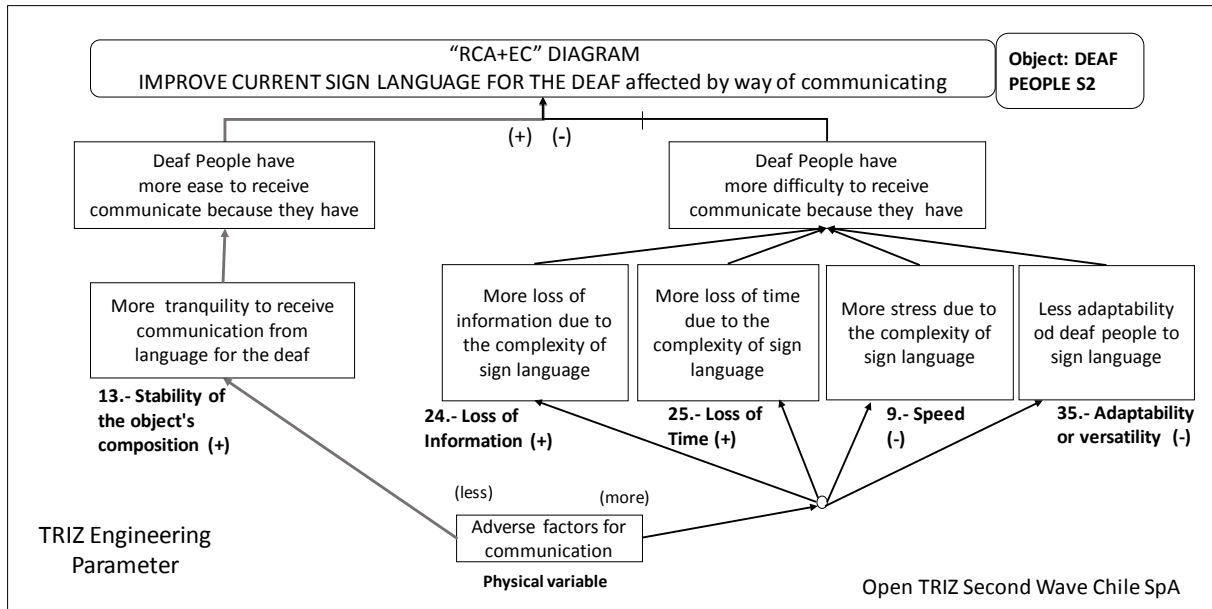


Fig. 4 “RCA+EC” Diagram Improve Current Sign Language Object S1 Deaf People

Table 5  
Sub-matrix of Contradictions to Improve Current Sign Language. Object S2 Deaf People

Par. Improve / Attenuate or preserve	Var.	24.- Loss of Information	25.- Loss of Time	11.- Stress or pressure	35.- Adaptability or versatility	13.- Stability of the object's composition	Sum%(Fij)
24.- Loss of Information	Fij		WT.9	-	WT.15	-	10%
24	IPs.	0,0,0,0	24,26,28,32	0,0,0,0	0,0,0,0	0,0,0,0	
25.- Loss of Time	Fij	WT.9		WT.13	WT.4	WT.14	41%
25	IPs.	24,26,28,32	0,0,0,0	37,36,4,0	35,28,0,0	35,3,22,5	
11.- Stress or pressure	Fij	WT.15	WT.12		WT.2	WT.3	75%
11	IPs.	0,0,0,0	37,36,4,0	0,0,0,0	35,0,0,0	35,33,2,40	
35.- Adaptability or versatility	Fij	-	WT.5	WT.7		WT.11	41%
35	IPs.	0,0,0,0	35,28,0,0	35,16,0,0	0,0,0,0	35,30,14,0	
13.- Stability of the object's composition	Fij	-	WT.7	WT.6	WT.1		72%
13	IPs.	0,0,0,0	35,27,0,0	2,35,40,0	35,30,34,2	0,0,0,0	
Sum%(Fij)		10%	49%	33%	100%	48%	

According to the relevant inventive principles identified, Table 5 y 6, when evaluating the Object: DEAF PEOPLE, the solution should be oriented and focused on:

- (IP 35) Change the composition or condition by adding components to DEAF PEOPLE.
- (IP 30) Use for DEAF PEOPLE communication flexible shells and thin films, simple physical shapes or simple ways to apply.
- (IP 34) Make portions of DEAF PEOPLE that have fulfilled their functions go away (discard message after “to listen”).



- (IP 10) Perform, before it is needed, the required change of language for the deaf (either fully or partially).
- (IP 2) Add new characteristics or properties to DEAF PEOPLE.
- (IP 33) To avoid stress and achieve stability to DEAF PEOPLE use its most compatible parts to deliver information.

Table 6

Recommended Solution Table to Improve Current Sign Language. Object S2 Deaf people

Solution table	Essencial Contradiction	Supplementary Contradictions with Preferred Parameters (*)			
Eng. Par. to Improve	13.- Stability of the object's composition	11.- Stress or pressure	11.- Stress or pressure	25.- Loss of Time	11.- Stress or pressure
Eng. Par. to Attenuate or Preserve	35.- Adaptability or versatility	35.- Adaptability or versatility	13.- Stability of the object's composition	35.- Adaptability or versatility	25.- Loss of Time
Weight priority	WT.1	WT.2	WT.3	WT.4	WT.12
IPs. Priority 1	35	35	35	35	37
IPs. Priority 2	30	0	33	28	36
IPs. Priority 3	34	0	2	0	4
IPs. Priority 4	2	0	40	0	0

- (IP 37) Apply energy fields to DEAF PEOPLE to expand information received to reach the brain of DEAF PEOPLE.
- (IP 24) For communication with DEAF PEOPLE use intermediary carrier article or intermediary process. (IP 24).
- (IP 28) Replace in DEAF PEOPLE mechanical means with a sensory means. Use electric, magnetic, and electromagnetic fields to interact with DEAF PEOPLE language.

Particular conclusion: Deaf people must add components, new features and intermediary processes to process sensitive effects from information transmitter. Sensitive parts of the human body must be used.

### 3.2. Technological Research

The analyzes carried out so far show the key guidelines for the solution.

Now we will review technological research in the field of communication for the deaf , in accordance with the guidelines.

Headphones” Convert Sound Into Vibration  
So The Deaf Can Experience Music [4]

<http://www.good.is/articles/headphones-for-the-deaf>

We can appreciate that the application of vibratory fields to the human body (IP28) is an advance that indicates a feasible form of solution for a new language of the deaf.

But, apparently it has not been used for this purpose, since the transmission of sound of words seems to be more complex to identify.

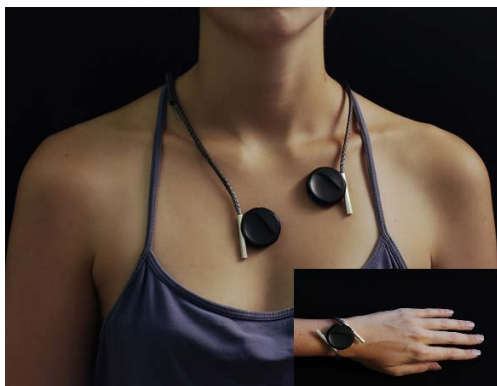


Image 1

On the other hand studies of vibration detection of in human beings indicate the following:

Effects of aging on vibration detection thresholds at various body regions

<https://bmcgeriatr.biomedcentral.com/articles/10.1186/1471-2318-3-1> [5]

Testing was performed on 22 young adults (11 females and 11 males; 17–27 years old,  $\mu \pm \delta$ , 20.2 years  $\pm$  2.2) and 22 elderly adults (11 females and 11 males; 55–90 years old,  $\mu \pm \delta$ , 68.6 years  $\pm$  10.6). All subjects were in good general health, without any history of upper limb nerve lesions, peripheral vascular disease or diabetes mellitus.

Image 2

Results Vibration detection thresholds (dB)

The fingertip was the most sensitive site for vibrotactile detection at both frequencies in a substantial majority of subjects. The older group of subjects showed significantly higher detection thresholds for both frequencies at all sites, except the fingertip, when compared to young subjects.

Stimulus and age group	Group size	Fingertip		Forearm		Shoulder		Cheek	
		n	μ	SE	μ	SE	μ	SE	μ
30 Hz									
young	22	22.58	0.88	32.09	0.92	32.35	0.90	29.10	0.94
elderly	22	25.51	1.34	40.59	1.32	43.46	1.43	40.65	1.79
200 Hz									
young	22	13.80	1.02	23.20	0.89	23.12	0.76	21.78	0.86
elderly	22	13.33	1.62	29.12	1.76	30.80	2.23	34.03	2.11

Additionally, another study points out:

Brains of deaf people rewire to ‘hear’ music / UW radiologist Dean Shibata, 2001

87th Scientific Assembly and Annual Meeting of the Radiological Society of North America (RSNA)

<http://www.washington.edu/news/2001/11/27/brains-of-deaf-people-rewire-to-hear-music> [6]

“Shibata performed the research while on the faculty at the University of Rochester School of Medicine in New York. The deaf students in the study came from the National Technical Institute of the Deaf at the Rochester Institute of Technology. Shibata used functional magnetic resonance imaging (fMRI) to compare brain activity between 10 volunteers from the college and 11 volunteers with normal hearing. They agreed to let Shibata scan their brains while subjected to intermittent vibrations on their hands.

Both groups showed brain activity in the part of the brain that normally processes vibrations. But in addition, the deaf students showed brain activity in a golf ball-sized area, the auditory cortex,

otherwise usually only active during auditory stimulation. The people with normal hearing did not show such brain activity.

“These findings illustrate how altered experience can affect brain organization. It was once thought that brains were just hard-wired at birth, and particular areas of the brain always did one function, no matter what else happened. It turns out that, fortunately, our genes do not directly dictate the wiring of our brains. Our genes do provide a developmental strategy — all the parts of the brain will be used to maximal efficiency, Shibata says.

The findings may explain how deaf people can enjoy music and how some become performers. Shibata uses an example from the National Technical Institute of the Deaf in Rochester, a college where musical productions are an important part of the deaf culture. Audience members attending musicals are provided with balloons which they can hold on their fingertips in order to “feel” the musical vibrations.”

### 3.3. First solution approach - Sound Vibration Language for the Deaf

TRIZ&TOC TOOL allows innovation based on the analysis of solutions that do not meet the desired objective. As we see before, there is a vibration communication system that allows the deaf to listen to music, sound vibration language, but apparently it does not work for spoken language. We will evaluate this condition, recognizing the existing limitations and we will postulate the impossible case, if these limitations did not exist then we could understand the spoken language. We want to know what we need to improve so that deaf people hear spoken language through vibrations.

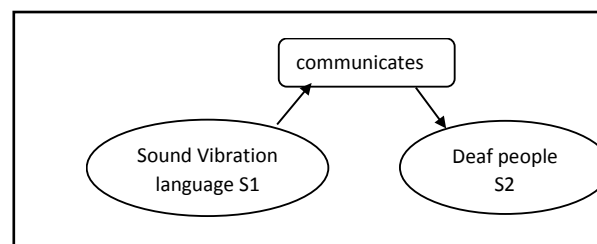


Fig. 5 Substance/Field Analysis Sound vibration Language for the Deaf

#### 3.3.1 Sound Vibration Language for the Deaf / Evaluation Object S2 DEAF PEOPLE

RCA+EC diagram to be evaluated is shown in Fig.6.

Sub-matrix and recommended solution table are shown in table 7 and 8.

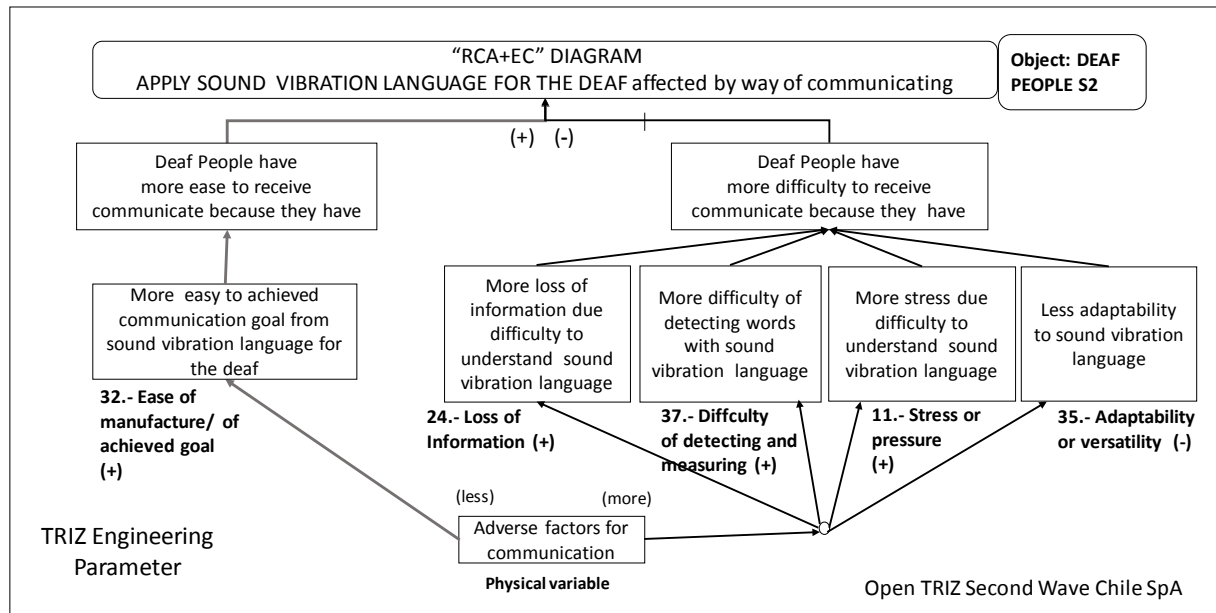


Fig. 6 "RCA+EC" Diagram Improve Sound vibration Language Object S2 Deaf People

Table 7

Sub-matrix of Contradictions to Sound vibration Language. Object S2 Deaf People

Par. Improve / Attenuate or preserve	Var.	24.- Loss of Information	37.- Difficulty of detecting and measuring	11.- Stress or pressure	35.- Adaptability or versatility	32.- Ease of manufacture/of achieved goal	Sum%(Fij)
24.- Loss of Information	Fij		WT.7	WT.17	-	WT.11	23%
24	IPs.	0,0,0,0	35,33,0,0	0,0,0,0	0,0,0,0	32,0,0,0	
37.- Difficulty of detecting and measuring	Fij	WT.15		WT.2	WT.9	WT.16	62%
37	IPs.	35,33,27,22	0,0,0,0	35,36,37,32	1,15,0,0	5,28,11,29	
11.- Stress or pressure	Fij	-	WT.12		WT.4	WT.3	64%
11	IPs.	0,0,0,0	2,36,37,0	0,0,0,0	35,0,0,0	1,35,16,0	
35.- Adaptability or versatility	Fij	-	WT.6	WT.8		WT.13	36%
35	IPs.	0,0,0,0	1,0,0,0	35,16,0,0	0,0,0,0	1,13,31,0	
32.- Ease of manufacture/of achieved goal	Fij	WT.14	WT.5	WT.1	WT.10		79%
32	IPs.	32,24,18,16	6,28,11,1	35,19,1,37	2,13,15,0	0,0,0,0	
Sum%(Fij)		11%	59%	100%	44%	50%	

Table 8

Recommended Solution Table to Improve Sound Vibration Language. Object S2 Deaf people

Solution table	Essencial Contradiction	Supplementary Contradictions with Preferred Parameters (*)			
Eng. Par. to Improve	32.- Ease of manufacture/achieved goal	37.- Difficulty of detecting and measuring	32.- Ease of manufacture/achieved goal	35.- Adaptability or versatility	32.- Ease of manufacture/achieved goal
Eng. Par. to Attenuate or Preserve	11.- Stress or pressure	11.- Stress or pressure	37.- Difficulty of detecting and measuring	11.- Stress or pressure	35.- Adaptability or versatility
Weight priority	WT.1	WT.2	WT.5	WT.8	WT.10
IPs. Priority 1	35	35	6	35	2
IPs. Priority 2	19	36	28	16	13
IPs. Priority 3	1	37	11	0	15
IPs. Priority 4	37	32	1	0	0

According to the relevant inventive principles identified when evaluating the Object: DEAF PEOPLE, table 7 and 8, the solution should be oriented and focused on:

- (IP 35) Change the composition or condition by adding components to DEAF PEOPLE.

- (IP 19) DEAF PEOPLE must receive variant information in time, periodic or pulsating to improve message quality.
- (IP 1) Divide DEAF PEOPLE or parts into independent points to improve vibration capture.
- (IP 37) Apply energy fields to DEAF PEOPLE to expand information received to reach the brain of DEAF PEOPLE.
- (IP 36) Use phenomena that occur during changes of state to improve information reception by DEAF PEOPLE.
- (IP 32) Change the perception, appearance, or form of DEAF PEOPLE for information reception.
- (IP 6) Make a part or total DEAF PEOPLE perform multiple functions.
- (IP 28) Replace in DEAF PEOPLE mechanical means with a sensory means. Use electric, magnetic, and electromagnetic fields to interact with DEAF PEOPLE.

Particular conclusion: For DEAF PEOPLE, it is necessary to change the way information is received, use its other sensory capabilities, receive information in a pulsating way, be multifunctional and evolve in replacement of mechanical means by sensory means and / or sensitive fields.

### 3.4. Final solution - Vibration Sensory Language for the Deaf

"Sound Vibration Language for the Deaf" analysis has allowed us to validate the use vibration sensitive parts of the deaf people and segmented vibrations for deaf language, in a first phase of evolution. However, some doubts persist for this new language:

How to make a design that is not very complex ?

How to get it to be low cost?

How to ensure good quality communication?

How to better adapt new language to the deaf?

How to make a new reliable language?

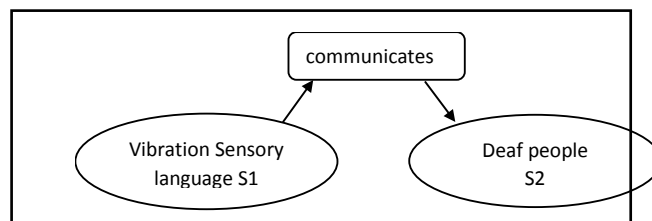


Fig.7 Substance/Field Analysis Vibration Sensory Language for the Deaf

#### 3.4.1 Vibration Sensory (VS) Language For The Deaf / Evaluation Object S1 Vibration Sensory Language

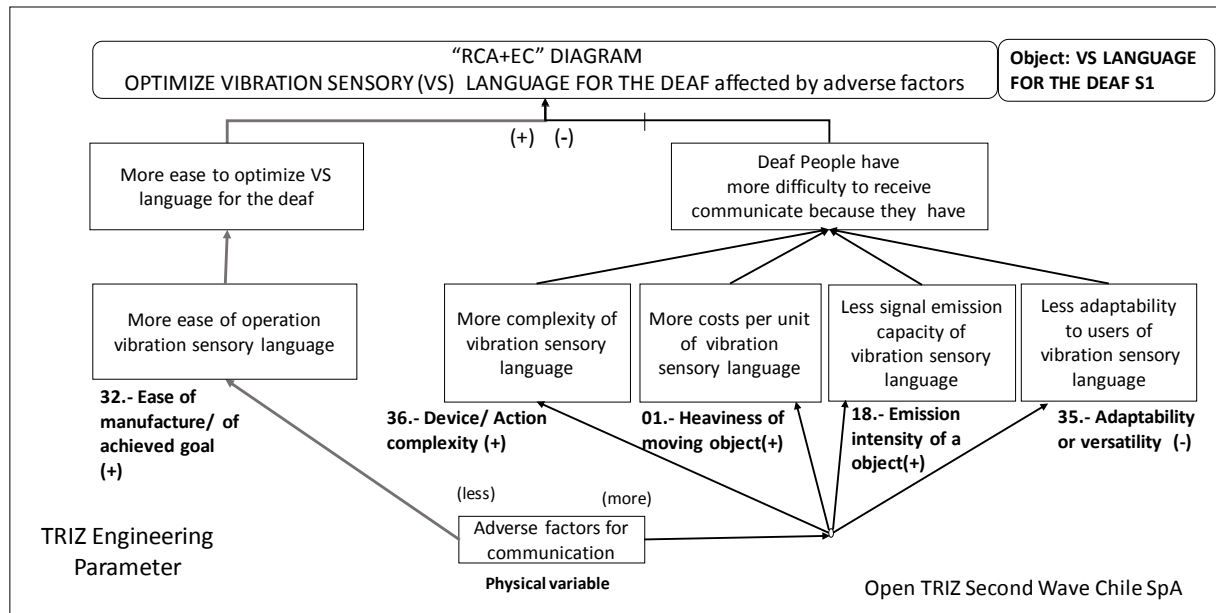


Fig. 8 “RCA+EC” Diagram Improve Vibration Sensory Language Object S1 VS Language

Table 9

Sub-matrix of Contradictions to Vibration Sensory Language Object S1 VS Language

Par. Improve / Attenuate or preserve	Var.	36.- Device/Action complexity	01.- Heaviness of moving object	18.- Emission intensity of a object	35.- Adaptability or versatility	33.- Ease of operation	Sum%(Fij)
36.- Device/Action complexity	Fij		WT.18	WT.17	WT.6	WT.11	57%
36	IPs.	0,0,0,0	26,30,34,36	24,17,13,0	29,15,28,37	27,9,26,24	
01.- Heaviness of moving object	Fij	WT.18		WT.8	WT.16	WT.20	45%
1	IPs.	26,30,36,34	0,0,0,0	19,1,32,0	29,5,15,8	35,3,2,24	
18.- Emission intensity of a object	Fij	WT.12	WT.9		WT.2	WT.10	84%
18	IPs.	6,32,13,0	19,1,32,0	0,0,0,0	15,1,19,0	28,26,19,0	
35.- Adaptability or versatility	Fij	WT.5	WT.7	WT.1		WT.13	100%
35	IPs.	15,29,37,28	1,6,15,8	6,22,26,1	0,0,0,0	15,34,1,16	
33.- Ease of operation	Fij	WT.15	WT.3	WT.4	WT.14		78%
33	IPs.	32,26,12,17	25,2,13,15	13,17,1,24	15,34,1,16	0,0,0,0	
Sum%(Fij)		56%	78%	98%	74%	57%	

"RCA + EC" diagram shown in Fig. 8 below contains two parameters that are applied according to the new universal description proposed in this paper.

The first of them refers to N°1 Engineering parameter , expressed as heaviness of object, in this case economic heaviness and the second refers to No. 18 engineering parameter, now generically described as the emission intensity of an object.

For N°1 Engineering parameter , we see that recommendations that arise have logic and common sense of costs, for example WT.7 contradiction say us to improve the adaptability to new vibration sensory language and to attenuate the costs of this new communication system.

For N°18 Engineering parameter, it is remarkable recommendation WT.9, which tells us we should improve the emission of new vibration sensory language and attenuate costs of this new communication system, by sending pulses of information, inventive principle No. 19, segmentation of the message, inventive principle No. 1, and change of appearance or perception of vibration sensory system to improve communication, inventive principle No. 32.

About recommendations for problem formulated, according to the relevant inventive principles identified when evaluating the Object: VS Language for the Deaf, table 9 and 10, the solution should be oriented and focused on:

Table 10

Recommended Solution Table to Improve Vibration Sensory Language Object S1 VS Language

Solution table	Essencial Contradiction	Supplementary Contradictions with Preferred Parameters (*)			
Eng. Par. to Improve	35.- Adaptability or versatility	33.- Ease of operation	35.- Adaptability or versatility	35.- Adaptability or versatility	01.- Heaviness of moving object
Eng. Par. to Attenuate or Preserve	18.- Emission intensity of a object	18.- Emission intensity of a object	36.- Device/Action complexity	01.- Heaviness of moving object	18.- Emission intensity of a object
Weight priority	WT.1	WT.4	WT.5	WT.7	WT.8
IPs. Priority 1	6	13	15	1	19
IPs. Priority 2	22	17	29	6	1
IPs. Priority 3	26	1	37	15	32
IPs. Priority 4	1	24	28	8	0

- (IP 6) Make that components of VS LANGUAGE for the deaf perform multiple functions to improve adaptability and reduce costs.
- (IP 22) Eliminate a harmful primary action by adding to VS LANGUAGE another counteracting harmful action to improve vibration emission quality from VS language.
- (IP 26) To better adaptability of VS LANGUAGE on spoken message transformation to vibrations, obtain an easy-to-use message copy to improve vibration emission quality.
- (IP 1) Segment vibration emission to improve adaptability par(35,18) and for VS LANGUAGE put together several components into one to reduce costs par(35,1).
- (IP 13) Select the best way to transmit vibration, e.g., if frequency is continuous, change to variable frequency per segment to improve vibration emission quality.
- (IP 17) Use a multi-vibration arrangement of objects instead of a single-vibration arrangement to improve vibration emission quality.
- (IP 24) For communication VS LANGUAGE use intermediary carrier article or intermediary process to improve vibration emission quality.
- (IP 15) Design the characteristics of VS LANGUAGE to find an optimal operating condition.
- (IP 29) To better adaptable language use digital technology to interact with VS LANGUAGE, e.g., voice to text software.
- (IP 37) Apply energy fields to VS LANGUAGE to expand by sensitive vibrations the message to be sent to DEAF PEOPLE.
- (IP 28) Use electric, magnetic, and electromagnetic fields to improve adaptability of VS LANGUAGE.
- (IP 8) To compensate cost of VS LANGUAGE merge it with other objects that provide an effect that improves the current situation. Example, use open source technology.
- (IP 19) For a better quality of VS LANGUAGE improve pulsating signals will activate human body of deaf people.

#### 4.- Conclusions & Proposed solution

The process of systematic innovation exposed, allows to express following conclusions:

Using the "RCA + EC" diagram allows an accurate formulation of the problem, creating a mental map that facilitates understanding and avoids interpretation errors.

Use of algorithm AATRIZINVENTOR focuses in an appropriate way the solutions for a first scope, accelerates the work as long as there is full knowledge of the problem to be solved and properly related inventive principles recommended with state of the art technology applicable to the problem to obtain solution.

Use of engineering parameters and inventive principles with universal description adequately respond and facilitate problem compression and its solution in particular context that are applied.

Search for optimal solution requires considering evaluation of both objects that interact in a system, whose initial joint solution is integration of both solutions.

Search for optimal solution requires considering evaluation of both objects that interact in a system, whose initial solution is integration of both solutions.

The initial solution may not be definitive, it is necessary to perform contingency analysis of that solution to optimize it and obtain better information for the final solution design.

The more advanced contingency analysis, the solution is more accurate.

Analysis presented in this paper has allowed the development of a prototype in the testing phase, which shows that recommendations obtained with TRIZ & TOC TOOL are reliable and accurate.

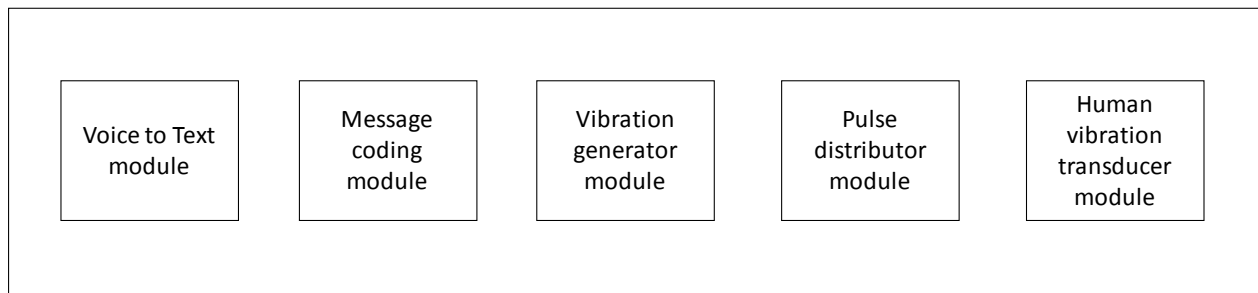
It is estimated that there are 70,000,000 deaf people in the world [7], taking advantage of technological advances to improve communication with the deaf is a challenge that should not be postponed.

A low-cost technological solution is possible.

Prototype developed with this paper has been presented at the 14th International Conference. September 13-15, 2018, Lisbon, Portugal.

The developed solution is expressed in the following diagram.

Modular design of receiving equipment attached to the deaf person's body



This solution breaks old paradigm, now we say does not send sound to the deaf, sends information.

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**Communicating Author:** [vinajev@gmail.com](mailto:vinajev@gmail.com)

**TRIZfest 2018**  
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**CONTRADICTIONS OF USER INTERFACE (UI)**

Valeriy Prushinskiy

*Samsung Electronics, Suwon, South Korea*

**Abstract**

This article discusses contradictions of User Interface (UI) in process of development of connected products in framework of Internet of Things (IoT) trend. Transition to connected devices (IoT) co-exists with another powerful trend: transition from single device to multi-device User Experience (UX). That means, that users must have opportunity to access their IoT devices and perform their activity not only from smartphones, but also from tablets, PCs, TVs, wearables and other smart home devices. The article considers both examples of resolving contradictions of User Interfaces for single devices and resolving contradictions of User Interfaces for multi-device environment.

Keywords: UI contradictions, contradictions of IoT devices, multi-device UX.

**1. Introduction**

The user interface is part of human-machine interaction that provides means by which the user and computer system or machine interact, usually by means of input devices and software. Currently, physical part of the user interface of the modern products is presented by touchscreens, keyboard, mouse, membrane switches and many other devices that user can see, touch and activate by various body parts [1].

Traditionally, human-machine interaction is accomplished by arms, wrist, fingers, movements of torso, legs, feet, eyes, face, tongue, lip, skin, head and other body parts can be described by Fitts' law [2]. Originally, Fitts proposed how to quantify the difficultness of selection of target. Target is main part of the user interface for interaction with machine, especially for modern touch screen interfaces activated by fingers, that is why it is important to consider Fitts's original Index of Difficulty (ID, in bits):

$$ID = \log_2 \left( \frac{2D}{W} \right) \quad (1)$$

Where:

D is distance to the target,

W is width of target.

In order to measure human performance, Fitts proposed Index of Performance (IP, in bits per second). This index combines Index of Difficulty (ID) and movement time (MT, in seconds):

$$IP = \left( \frac{ID}{MT} \right) \quad (2)$$

where:

IP is index of difficulty,

MT is movement time.

In this article, various aspects of user interaction with modern display devices, such as smartphones, tablets, television sets and smart watches are considered from point of view of contradictions, appearing in process of development of user interfaces.

## 2. Contradictions of User Interface (UI)

### 2.1. Small and Medium Display Devices

In TRIZ, Physical Contradiction is two opposite requirements placed upon a single physical parameter of an object. These requirements are caused by the conflicting parameters of a Technical Contradiction. Meaning of Physical Contradiction is that requirements toward certain part of the system are mutually exclusive, e.g.: cold and hot, mobile and motionless, long and short, flexible and rigid etc. Physical contradictions can be resolved by separation in space, separation in time, separation in structure (in system level) and separation on conditions [3].

Very simplified, applying Fitts law for modern display devices, one can say that bigger target is easier for user to reach, smaller target is more difficult to reach. Also, shorter distance to target, easier for user to reach it. Moreover, when interaction by fingers is considered, the fingers are too big for small screen, they are obstructing the target, so that user cannot see image under the finger.

For reliable interaction with modern touchscreens, diameter of the touch area of the finger should be at least 8 mm. That is why, when virtual QWERTY keyboard is placed on the screen of small size smartphones, following contradiction can be considered:

Keyboard button has to be small, so full-size QWERTY keyboard can be placed on the screen, and button has to be big, so it can be conveniently pressed by user's finger.



Fig. 1. Full-Qwerty keyboard UI problem for small displays

In solution described in US patent application USD621848, QWERTY keyboard with small buttons is placed on the screen. But when user is trying to press the button, screen “feels” the finger in close proximity and replace the image of the button by bigger one.

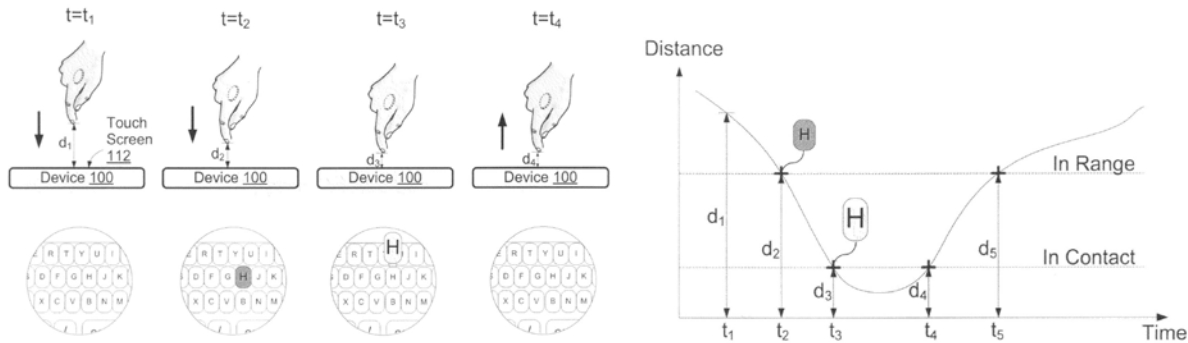


Fig. 2. Example of Full-Qwerty keyboard UI contradiction resolution in time

In this case, the contradiction is resolved in time, so that initially full QWERTY keyboard can be placed even on small display, and during interaction, size of the individual key is increased.

Same contradiction can be resolved differently, for example US patent application 20170082981 describes situation of transparent display or display device with touch screen on its back side.

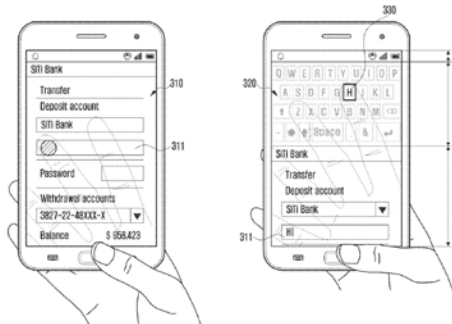


Fig. 3. Full-Qwerty keyboard UI contradiction resolution in space

In this case, user can see front side of the display while is not obstructed by his/her fingers. That is why he/she can “press” corresponding virtual button on the back side of the display device.

Above mentioned contradiction is described for pointing user interface, where user moving finger to a certain location on the screen. Another way to resolve this contradiction is transition to crossing-based user interface. This interface uses crossing of the target instead of pointing. Crossing was considered as promising alternative, assuming user can cross small target faster than point on them. Furthermore, several objects can be crossed at the same time. Based on this approach, “swiping” keyboard for touchscreen devices was proposed. During text entering by “swiping”, user draw the word in one continuous motion. It was expected that this keyboard should demonstrate substantial increase of speed.

Yet another approach of resolution of the same contradiction was development of different type of touchscreen QWERTY keyboard where neighbouring buttons are integrated. Each button contains two letters, while maintaining QWERTY arrangement.

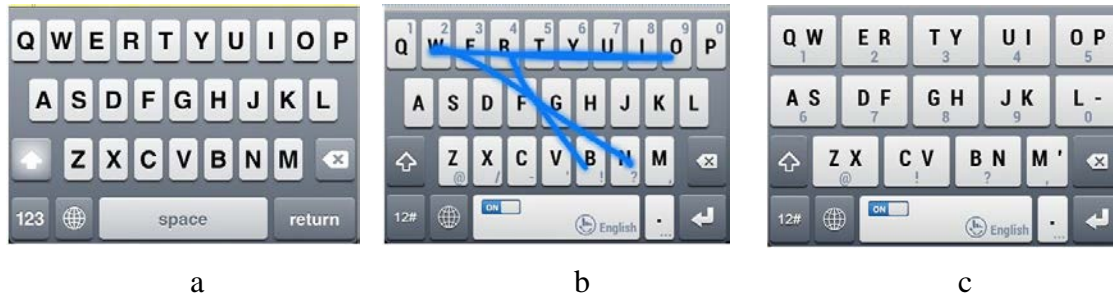


Fig. 4. QWERTY keyboards [4]: a) Standard QWERTY keyboard, b) “Swyping” QWERTY keyboard, c) QWERTY keyboard with integrated neighboring letters (Image source: [4])

Several variations of the QWERTY keyboards for mobile phones were tested for maximum entry speed in study [4]. Unfortunately, entering of a text by “swyping”, where user draw the word in one continuous motion didn’t demonstrate substantial increase of speed. According to research, standard smartphone QWERTY keyboard had mean entry speed of 54 wpm, “swyping” one demonstrated entry speed of 35.3 wpm and “integrated” one achieved 38.7 wpm.

## 2.2. Wearable Devices

Same contradiction “keyboard button has to be small, so full-size QWERTY keyboard can be placed on the screen, and button has to be big, so it can be pressed by user’s finger” is even more aggravated for wearable devices with smaller screens.

Study for validation of text entry for ultra-small touchscreens using a fixed cursor and movable keyboard was accomplished similarly, as it done for smartphone touchscreen keyboard [5]. Unfortunately, since UI elements are smaller, it is much harder to resolve this contradiction as it is done for smartphones. Text entry speed is varied between 8 and 10 wpm, which is 5-6 times slower than standard smartphone keyboard speed.

In case of interaction with small wearable touchscreen devices, most part of the screen is covered by finger, therefore touch UI is inefficient. Attempt for further resolution of contradiction was continued by introduction of crown or rotating bezel for improvement of smart watch UI. Finally, voice input was utilized as viable alternative for text input on small touchscreen display during text messaging.

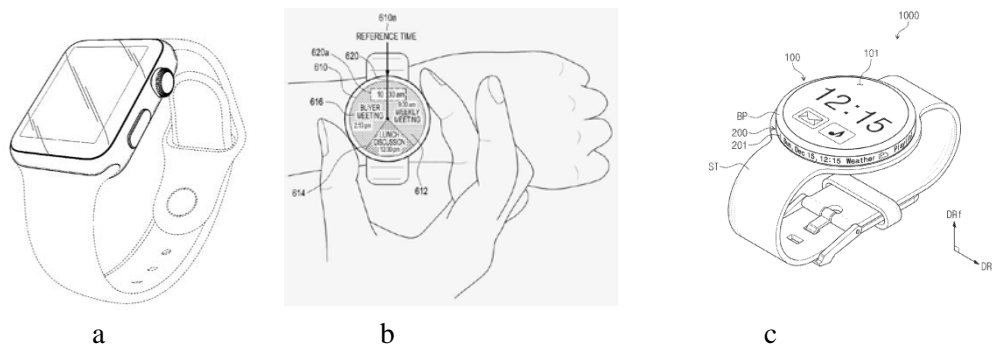


Fig. 5. Resolving UI contradiction in space for wearable devices: a) “crown” UI (Source: U.S. Patent US0D0728624), b) rotating bezel UI, c) “edge” UI (Source: US20170082982A1)

Alternatively, US patent 20170082982 describes display device and smart watch with front panel for displaying front image and round edge for displaying text and small images. However, in this case contradiction “edge has to be small and have to be big” is difficult to resolve.

### 2.3. Expansion of UI of Existing Devices

If existing device has touchscreen display, most of the efforts are focused on development visual and touch UI. However, there are other ways to expand UI of existing devices. Modern consumer devices provide opportunity to use many other sensors for UI. Nowadays, even smallest wearable devices like smartwatch may possess accelerometer, gyroscope, barometer, microphone, heart rate monitoring sensor, GPS and many other sensors. That is why it is recommended to try enhancement of UI based on more efficient utilization of existing and new sensors. This activity can consist of following steps:

- List existing sensors of the device
- Classify fields, sensed by sensors based on MaTChEM approach, known in TRIZ
- List possible interacting user’s body parts, that can be utilized for activation of each existing sensor. Note, on this step, it is important to describe sub-systems of the corresponding body part
- Propose concept of new UI by building series of SU-Field models based on listed sensors, fields and body parts and sub-parts (Note: Utilization of Su-Fields models is proposed as easiest TRIZ-tool for this activity. Other TRIZ-tools can be utilized as required).

Transition from touch interface of smartwatch to gesture interface is illustrated by US patent application 20160091980 “Motion and gesture input from a wearable device”.

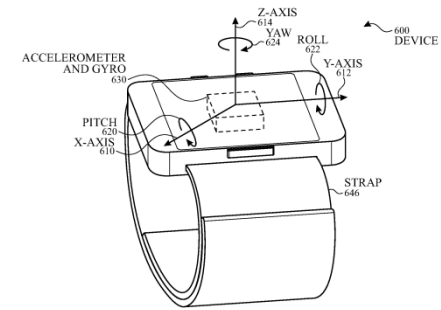


FIG. 6

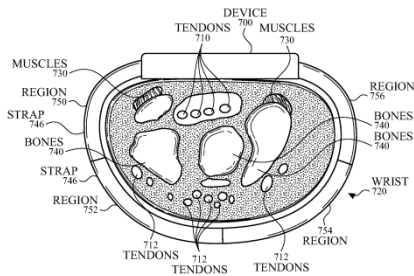


FIG. 7A

GESTURE INPUTS	COMMAND
1.HAND DOWN 2.PALM DOWN 3.PAUSE	DECLINE INCOMING PHONE CALL
HAND UP/DOWN AT A NORMAL SPEED	INCREASE OR DECREASE VOLUME ON SPEAKERS
HAND DOWN AT FAST SPEED	MUTE SPEAKERS
HAND WAVE ACROSS	SCROLL TO NEXT PAGE
HAND MOVEMENT TOWARDS USER	FIND PHONE OR ACTIVATE RINGER
THUMB AND LITTLE FINGERS EXTENDED WITH ALL OTHER FINGERS FIXED	MAKE A PHONE CALL
1.FIXED FINGERS 2.EXTENDED FINGERS	UNLOCK CAR DOOR (WHILE USER APPROACHING OR CLOSE TO A CAR)

FIG. 9A

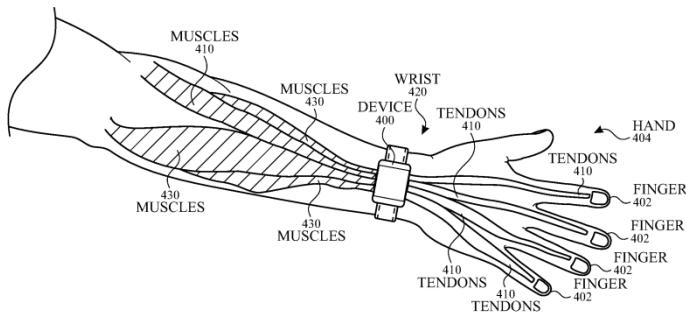


FIG. 4

Fig. 7. Gesture UI for wearable devices based on inertial sensors

(image source US 20160091980)

Due to limitations of small size of the touch screen, one can list potentially available sensors, such as accelerometer and gyroscope, that can detect motion and gestures. Su-Field model will include inertial sensor of wearable device, mechanical field and hand. Since the wearable is located on user's hand, it is possible to describe gesture input based on these sensors by detection of movement of the hand up, down or waving.

Similarly, one can begin building of Su-Field model starting from the user sub-parts, for example, if we select fingers of the hand, controlled by tendons or muscles, we should add sensor to acquire signals from them. In this case, our wearable device may include myoelectric sensors of electrodes, so that electrical signal from tendons can be obtained.

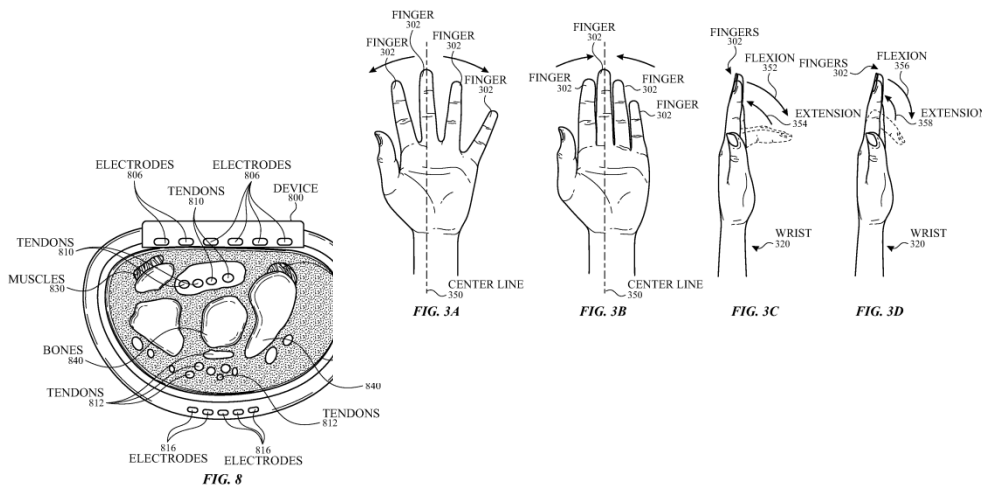


Fig. 8. Gesture UI for wearable devices based on myoelectric sensors or electrodes

(image source US 20160091980)

### 3. Influence of Internet of Things (IoT)

Until recently, most of the consumer devices are considered a standalone device. Currently, most of the users possess multiple connected devices like smart watch, smartphone, tablets, TVs, notebooks and other devices, and user interfaces have to be developed for switching of consumption between these devices. From TRIZ point of view, this is transition from mono- to bi- and poly-systems, in user UI design it is known as designing multi-device experiences [6].

#### 3.1. Multi-Device User Experience

According to this approach, since many users own multiple connected devices, and they are already using them together or switching between them, to accomplish their goals. Since most of the home devices soon will be IoT devices, designers consider concept of ecosystem of connected devices. Mission of UI design is to provide continuous and complimentary user experience. For this, one approach is to offer basic user interface and user experience for each device, so that user continuing the same activity passing from one device to another. Another approach is to offer user interface that will create connected group of devices, where devices are complement each other.

Main contradiction of the multi-device UI is user interface elements have to be small for consumption by small displays of mobile devices, and user interface elements have to be big for consumption by big displays, like TV and PC screens. Also, UI have to be efficient for touch interface on small devices, and UI have to be efficient for pointing interface on large devices. These contradictions are resolved most efficiently by separation in structure (in system level).

Simplest answer here is to develop separate apps for each device. Native Apps will work best because they are specific to device and they work offline and highly integrated into the device.



Another approach is Web Applications, which provide different UI depending of device.

As usually, there is hybrid approach, where there is combination of native apps and web apps. This approach has advantage of keeping single software codes for all devices of the ecosystem.

#### Consistent Design



#### Continuous Design



#### Complementary Design



Fig. 9. Resolution of contradictions in structure (in separation on different system level): a) Consistent UI approach: The same content is provided for each and every device of the ecosystem with some adjustment for each device b) Continuous UI approach: end-to-end user experience that is distributed across devices c) Complimentary UI approach: connection between devices, so that they can work together (image source: [7])

According to continuous design approach UI can be split between multiple devices, optimizing different activities that user has to accomplish. In this case user can continue activity on different device, where the previous one left off. From TRIZ point of view, this looks like separation of user activity in time.

Complementary approach establish connection between multiple (at least two) devices at same time and place, so that devices work together to create user experience. In this case User Interface for control may be distributed between devices.

Summarizing, following approaches are currently utilized for resolving UI contradictions in multi-device environment [6]:

- Consistent. Same experiences are offered independently in each device (with minor adjustments to fit device traits)
- Complimentary - Collaborative. Experience is split simultaneously between devices. They complement each other, to collaboratively create the full experience.
- Complementary - Control. Primary experience takes place on a single device, whereas others can control aspects of it (usually remotely)
- Continuous. Experience is split simultaneously between devices. They complement each other to collaboratively create the full experience.

### 3.2. Hybrid Devices

In order to improve UI for consumption on-the-go, at home and in office, compact hybrid devices were proposed. Most of them are based on flexible and foldable displays and their contradictions are related to flexible displays. E.g. radius of bending of the display has to be small in order to keep compact form-factor and radius of display has to be big in order to prevent damage of display. Also,

general contradiction of on-the-go devices is that for emailing and texting is mobile display has to be big to accommodate “typing” area with full QWERTY keyboard and substantial “text/email” area, and mobile display has to be small for placement into the pocket. In addition, display has to be big enough for tablet devices for browsing at home or in office and small for on-the-go wearable device form-factor.

One of the possible resolutions of these contradictions by system transition is described in US patent application 2016246558. According to this patent application, display device can have compact, wearable, stand-up and unfolded form-factors, maximizing utilization of the display for convenient UI.

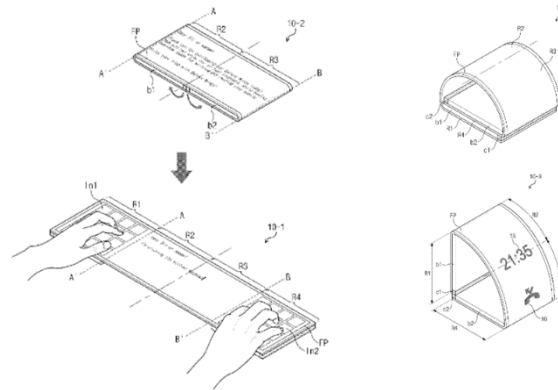
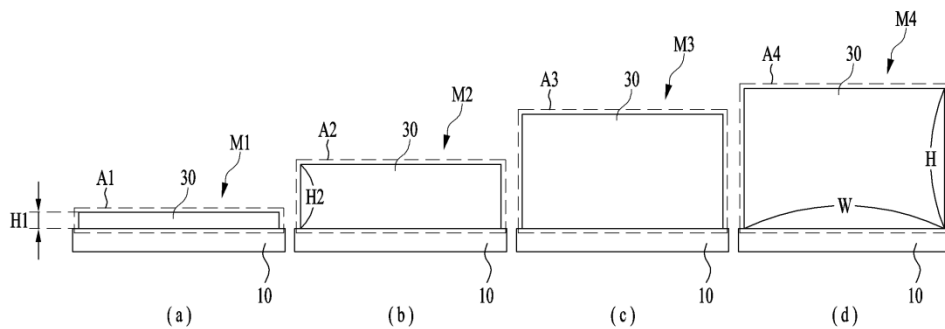


Fig. 10. Resolving UI contradiction by system transition with development of hybrid devices according to US patent application 2016246558

UI for controlling TV sets is different from UI of small and medium size display devices, because users are around 3 meters away from display. Currently, traditional UI is limited by the arrows of the remote control. Textual navigation through the text lists on TV screen should be big enough to be controlled by arrows and enter buttons of the remote control. Text entry via selection by arrows of remote control is problematic. Fortunately, in framework of multi-device UI, smartphones can be utilized for navigation and other activity, so now we can utilize familiar touch UI to control big screens.

Current state of rollable displays promises to change existing television sets. Large rollable display can be rolled up into the body of TV set. Depending of the size of display, expanded from the TV body, image size can be different. So, the size of the image should to be small in case of small unrolled part of the screen and should be big for large unrolled part of the screen. If TV can execute multitude of models for displaying different quantities of information according to the changes screen size, the image size ought to be matched to the screen size. The hybrid rollable display device can incorporate features of AI speaker, TV and music player.



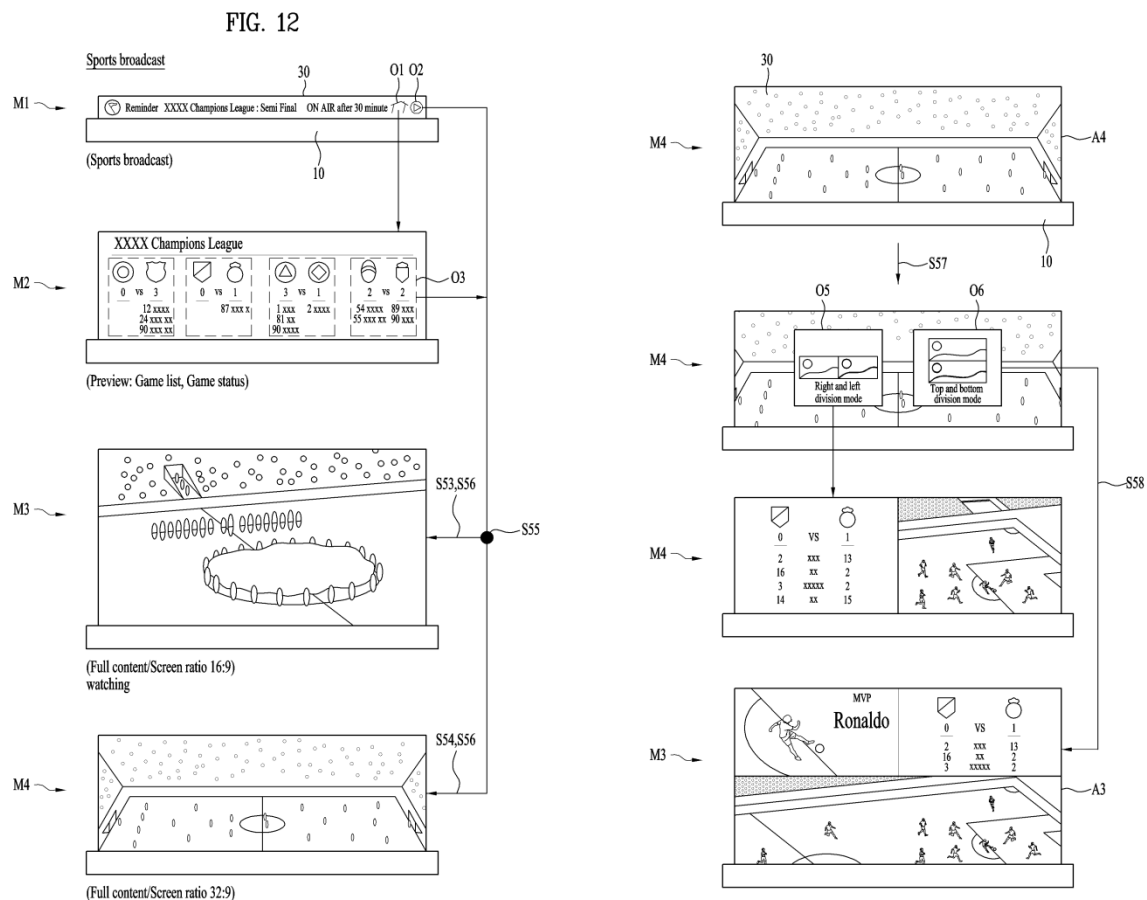


Fig. 11. Rollable display device according to US patent application 20170103735

Another approach is designing rollable TV with functions of IoT home control. In this case, depending of open size of the rollable display, the device can provide different UI for minimal, more detailed and full-house control of connected devices.

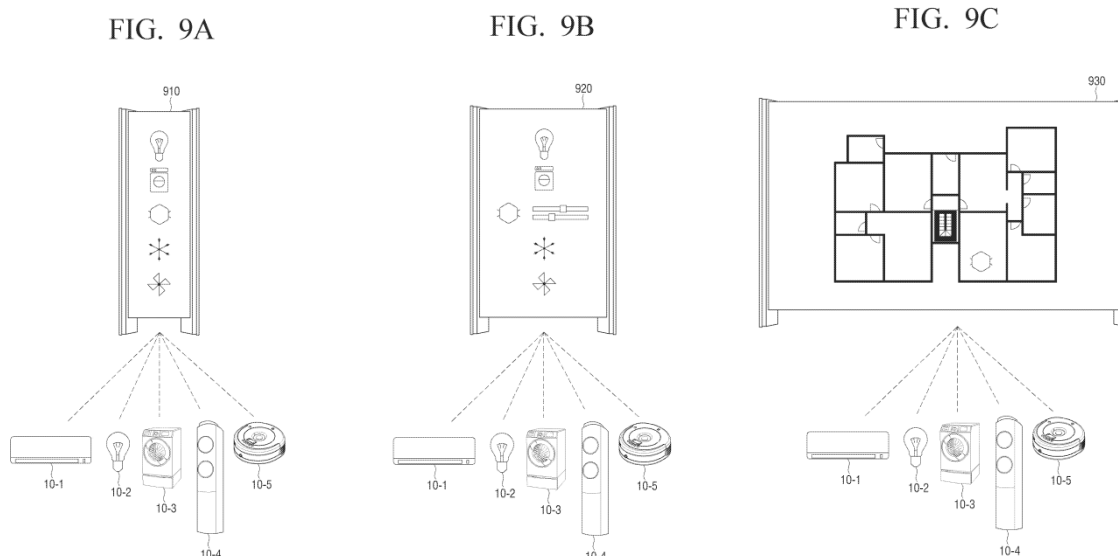


Fig. 12. UI of rollable display device according to US patent application 20160306534

## 4. Conclusions

Patent study was conducted for revealing of how contradictions of User Interfaces of display devices were resolved. Resolution of UI contradictions for small and medium size devices is mostly focused on touch-screen solutions, though it is saturated area with limited resources. In order to propose efficient solutions, it is recommended to study existing sensors of the device and focus on new ways of resolving contradictions, based on non-touch UI.

In case of resolution of UI contradictions for multi-device environment, patterns of non-uniform system development and matching of UI of devices of one ecosystem can be considered for development of more convenient interfaces.

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**Communicating Author:** valrush@hotmail.com

**TRIZfest 2018**  
**September 13-15, 2018. Lisbon, Portugal**

**A THEORETICAL MODEL AND ROADMAP FOR APPLYING  
TRIZ IN AN R&D ORGANIZATION**

Arthur Lok Project Director,  
*Innovation Empowerment Center, Shanghai, 200082, China*

**Abstract**

Applying TRIZ in a R&D organization is not an easy thing. In China, many big R&D organizations has tried to purchase TRIZ software and arrange TRIZ trainings. Personally I have accomplished a number of very successful TRIZ training camps, and solved tough technical problems. However, most organizations could not sustain the TRIZ momentum. What's the key underlying problem beneath this problem? Is there any way to tackle the problem? The author tries to do a systematic analysis on this problem, and provide two perspectives, technical perspective and organizational perspective on this problem. Then the author propose a universal organization model, a roadmap and a guideline for applying TRIZ in different organization. Also, the author introduced one case study to explore the success experiences and pitfalls in applying TRIZ.

Keywords: TRIZ process; Organizational Development; TRIZ champion; Capability Development

**1. Introduction**

Innovation and technology competitive advantages are playing a more and more important role among Chinese companies. Many corporate leaders are willing to invest in innovation-related processes, tools and training courses. They purchases and deploy software, hire talented people, and train the staffs to be more innovative. In this context, TRIZ is under rapid development in China. Many big R&D organizations has tried to purchase TRIZ software and arrange TRIZ trainings. For example, in the home appliance industry, most of the big companies, such as Haier, Midea, Fotile, etc., had already tried to implement TRIZ ever before. Personally I have accomplished a number of very successful TRIZ training camps, and solved tough technical problems. However, most organizations could not sustain the TRIZ momentum. If you ask the question: which companies are successful in using TRIZ in China? Very few companies would show up on the list. Why did this happen? The most common answer for this question were: lack of leadership attention; difficulty to learn and use TRIZ; and lack of TRIZ champions to promote TRIZ across the organization[1].

However, many engineers already know TRIZ as a very good tool in technology innovation, and many engineering leaders already planned about promoting TRIZ as the main tool for innovation in their organization. Among them, companies like Vivo, Joyoung, Huawei already trained people to use TRIZ to solve tough technical problems. But very few of them were successful. Just like the fact that Chinese companies spent decades to learn about project management and product management, it is not easy to implement new tools.

Is the implementation of TRIZ more difficult than project management or other tools? Or is it just a natural process of adopting a new methodology? In his book Diffusion of Innovations, Everett Rogers[2] described a phenomenon that people adopt a new idea or methodology in a different

speed. Only 2.5% of people are those who generate new ideas, and 13.5% of people are those who easily adopt new ideas, and they are usually those who introduce the idea to the majority of people.

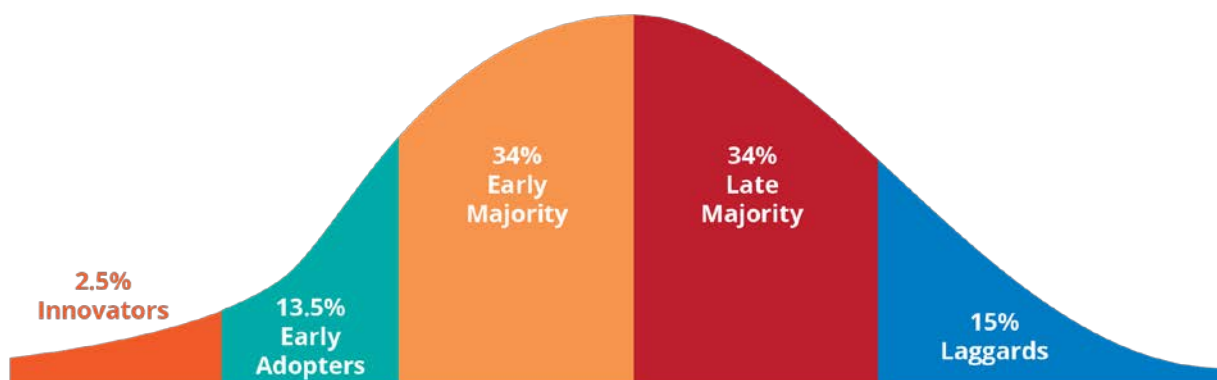


Fig. 1. Diffusion of Innovation

So what are the key problems for promoting and implementing TRIZ? To solve this problem, we need to know about the bottleneck problems that hold us back.

## 2. Criterial for TRIZ success in a R&D organization

What is the ideal status for implementing TRIZ? Before we answer this question, we need to understand what is the role of R&D, and what is the role of TRIZ. For an R&D organization, its essential role is to produce new technologies and design new products. So what is a successful R&D organization? The answer is: if it could produce sustainable technology core competences, then it is a success. So if we see a R&D organization as a machine, then the output of this machine is : great technology, great products, and great talents.

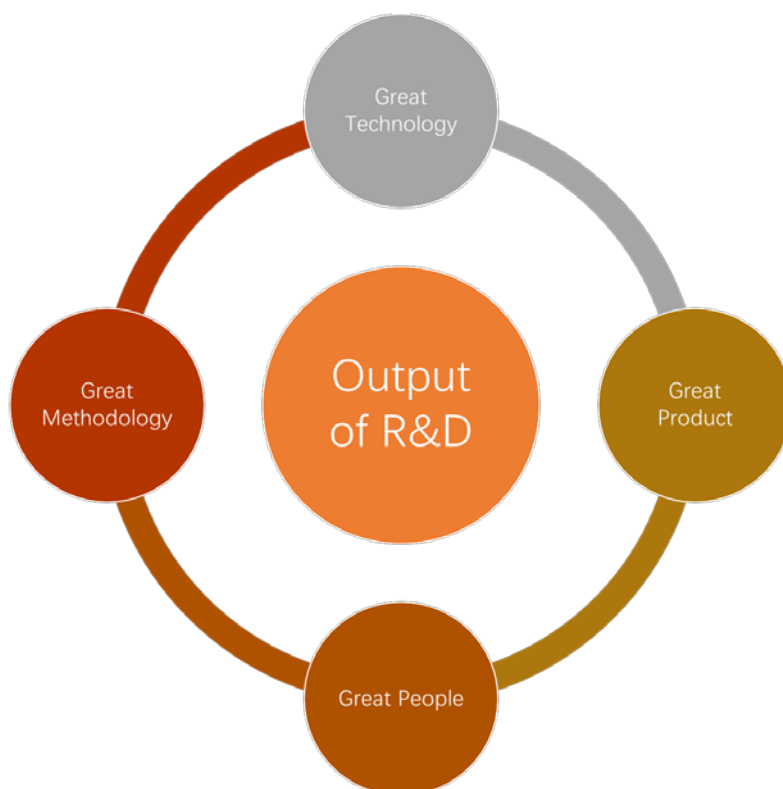


Fig. 2. Ideal output of an R&D Organization



Based on the previous literature[1], the author suggested the following criteria for the success of using TRIZ in a R&D organization.

- Coverage. The percentage of people who have received TRIZ training is a good measure for the success. The wider range of people we cover, the greater impact we exert to the organization.
- Usage. The number and percentage of projects which use TRIZ as a major tool to solve difficult problems is a good criterion to measure whether TRIZ is implemented. Usage of TRIZ in projects is usually an intermediate factor for TRIZ success. Because the more you use it, the more results you will gain from it.
- Result. The number of patents generated, the number of projects in which the application of TRIZ play an important role for the final solution is very important.
- Methodology. Whether we have a powerful and evolving methodology is an important factor for the success of TRIZ.
- Number of TRIZ champion. The number of qualified TRIZ champion is a factor that is highly correlated with the success of TRIZ implementation.
- Number of TRIZ engineers. The higher the number of TRIZ engineers is, the greater results the organization will achieve.
- Business impact. TRIZ-enabled revenues and profits is a measure for the business impact of TRIZ.

Based on this, the key measures of TRIZ success we could consider include: number of patents; number of commercialized patents; number of TRIZ projects; number of people who received TRIZ training; number of certified TRIZ professionals; revenues produced by TRIZ-enabled products, etc.

### **3. The Key Obstacles.**

In practice, very few organizations could overcome the difficulties during TRIZ implementation and become successful. While there are a lot of factors that have impact to the success of TRIZ, here are the main obstacles.

3.1 Lack of leadership support. To make it successful, we need to overcome the big obstacles from the organization and culture. If the corporate leaders are committed to the success of TRIZ, then it is much easier. However, corporate leaders have their own Key Performance Index (KPI), and they need to be convinced by the business results produced by TRIZ. However, in the early stage of applying TRIZ, it is not that easy to have obvious results. So there is a cycle about leadership support. If we have TRIZ results, then leaders pay more attention, and they are more willing to support, and then the TRIZ people could get more resources, and with these resources, the team will have stronger capabilities, and it is easier for the team to achieve results. However, this cycle could also be a vicious cycle, which means if we don't have practical results, leaders start to lose interest, and they are more reluctant to support, then it is even more difficult to generate results.

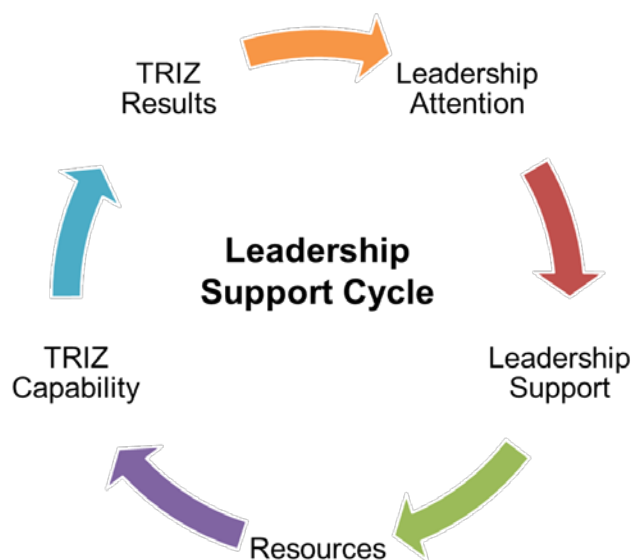
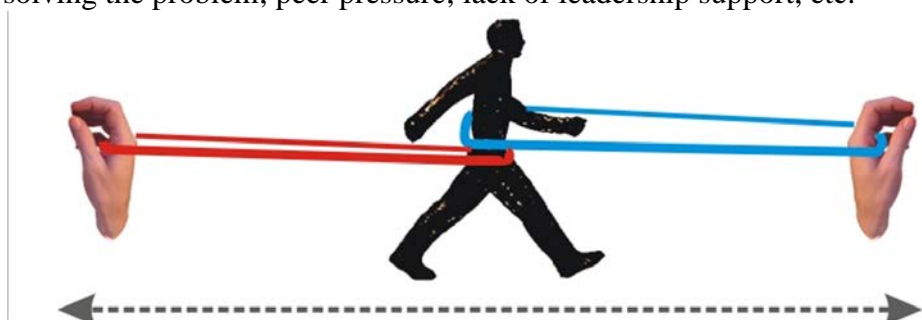


Fig. 3. Leadership Support Cycle

3.2 Poor participation. The participation of engineers are also very important. Because if they are passionate about TRIZ, then they use it and invest efforts in it. However, there are several important factors that influence their passion. If they get positive feedback from leaders or the market, then they will have greater power to solve the problems. Also, there are several obstacles: difficulty in learning and using TRIZ, especially in the early stage; Difficulty in solving the problem; peer pressure; lack of leadership support, etc.



1. Difficulty in learning TRIZ;
2. Difficulty in using TRIZ;
3. Difficulty in finding a solution;
4. Peer pressure;
5. Lack of leadership support

1. The 'Aha!' moment;
2. Problem solved;
3. Product success;
4. Recognition from leadership;
5. Reward.

Fig. 4. Tensions of a TRIZ people in an organization

3.3 Lack of proficiency of the TRIZ methodology. There are very few people who could really master the TRIZ methodology and generate results in practical projects, and if there is a lack of proficiency, then it becomes very difficult.

3.4 Not producing good results. If the TRIZ team did not produce good results, then it becomes very tough. People start to have doubt over the tools.

#### 4. Turning point: change and empowerment

How to make it easier for organizations to implement TRIZ? When we talk with different people, we found they usually feel powerless when using and promoting TRIZ in their organizations. And the author believes the most important thing is to empower TRIZ people.

How to empower TRIZ people? We found that if an engineer has the capability to use TRIZ, has the right tools to use, and generated very good result in a R&D project, then he is empowered, and he begins to be confident, thus has the energy to overcome even bigger challenges.

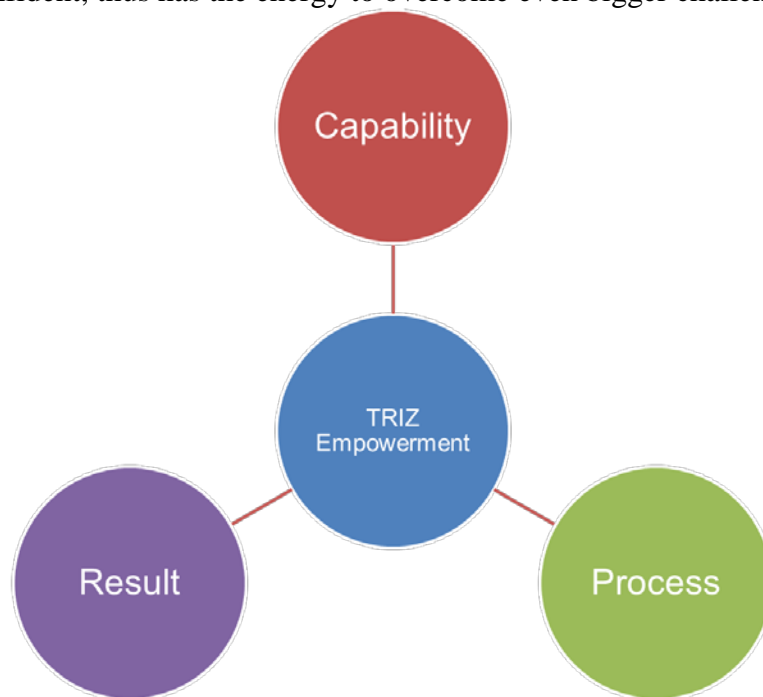


Fig. 5. TRIZ Empowerment Model

With this idea in mind, the author tried to design different levels of TRIZ empowerment. In Level 1, the engineers should have the capability which equals to MATRIZ level 1, and he is able to use a simplified TRIZ process, and generated some patents with TRIZ. In Level 2, engineers have more knowledge in TRIZ, which equals to MATRIZ level 2, and he is able to customize TRIZ process to specific problems, such as noise reduction problems, cost-down problems, etc. In this level, they are able to create new technologies with TRIZ and apply them in new products. In Level 3, engineers has the knowledge that equals to MATRIZ level 3, and he is able to use the full TRIZ process, and generate technical results that enales leading products.

	TRIZ Empowerment Level 1	TRIZ Empowerment Level 2	TRIZ Empowerment Level 3
Capability	MATRIZ Level 1	MATRIZ Level 2	MATRIZ Level 3
Process	Simplified TRIZ Process	Customized TRIZ Process	Full TRIZ Process
Results	Patents	New technology applied in product	Benchmark Product

Fig. 6. TRIZ Empowerment Levels

If we plan to empower engineers and help them upgrade the levels one by one, then it is much easier for them to overcome the tensions.

## 5. An organization model to tackle this problem.

After we understand how to help individual engineers master TRIZ tools and skills, we start to think about how to help implement TRIZ in organizations. Based on the authors' experience, to implement TRIZ in an organizations, people need to solve three problems at the same time.

Firstly, to implement TRIZ, we need to have key talents, who are TRIZ champions and TRIZ engineers. If we have very good TRIZ champions and TRIZ engineers, then most probably we will be able to apply TRIZ and generate a lot of results.

Secondly, we need to create a culture that encourage people to use TRIZ. For example, we could hold competitions about TRIZ projects, and spread the success stories. At the same time, we should set the KPIs and rewards for the TRIZ efforts.

Thirdly, we should create the right process for the projects. There are a lot of TRIZ tools, and not all the tools should be used in any projects. So we need to help customize the process.

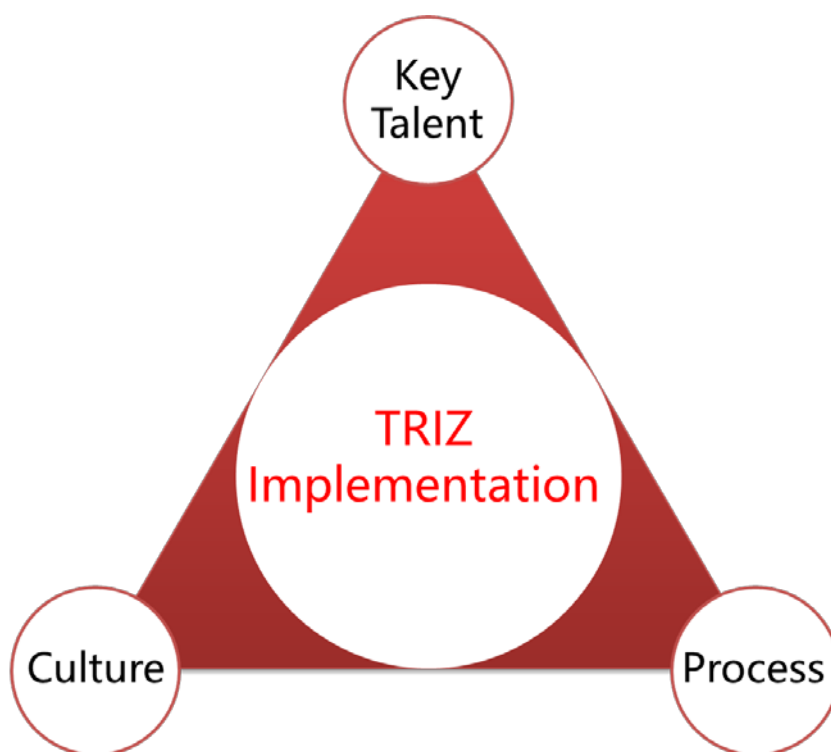


Fig.7. TRIZ Implementation Model

Morris[3] described a model of innovation culture in his book, which include three roles: Innovation Leader, Innovation Manager, and Creative Genius. Based on Morris's innovation culture model, the author suggest a model for the TRIZ organizations. There are 3 important roles related with TRIZ implementation.

The first role is the TRIZ Leader. So we should have the R&D vice presidents or chief engineers act as the sponsors for TRIZ. They will support the promotion and implementation of TRIZ.

The second role is the TRIZ champion. They are those who take care of promoting TRIZ and coaching others to use TRIZ. They are crucial for the success of TRIZ.

The third role is the TRIZ engineers. They are the bunch of engineers who use TRIZ actively to generate new technologies.

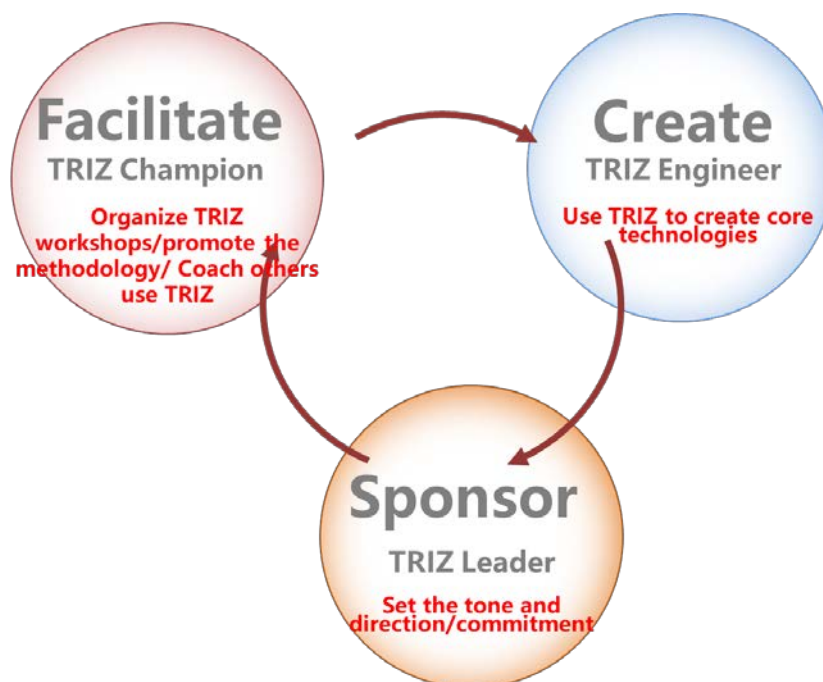


Fig. 8. Different roles in a TRIZ organization

## 6. A roadmap for TRIZ implementation in an R&D organization.

Based on the model and the thinking of change and empowerment, the author suggested a three-stage model for TRIZ implementation. In Stage 1, the focus is on generating practical results from TRIZ projects, because this sustains the momentum for TRIZ. In stage 2, the most important task is to train key talents, because the number of key TRIZ talents, such as TRIZ champions and TRIZ engineers, is a leading factor for the results. In stage 3, we need to focus on using TRIZ to create strategic advantages for the business.



Fig. 9. Three stages of TRIZ implementation.

Based on this model, the author suggested the following roadmap for implementing TRIZ in a R&D organization.

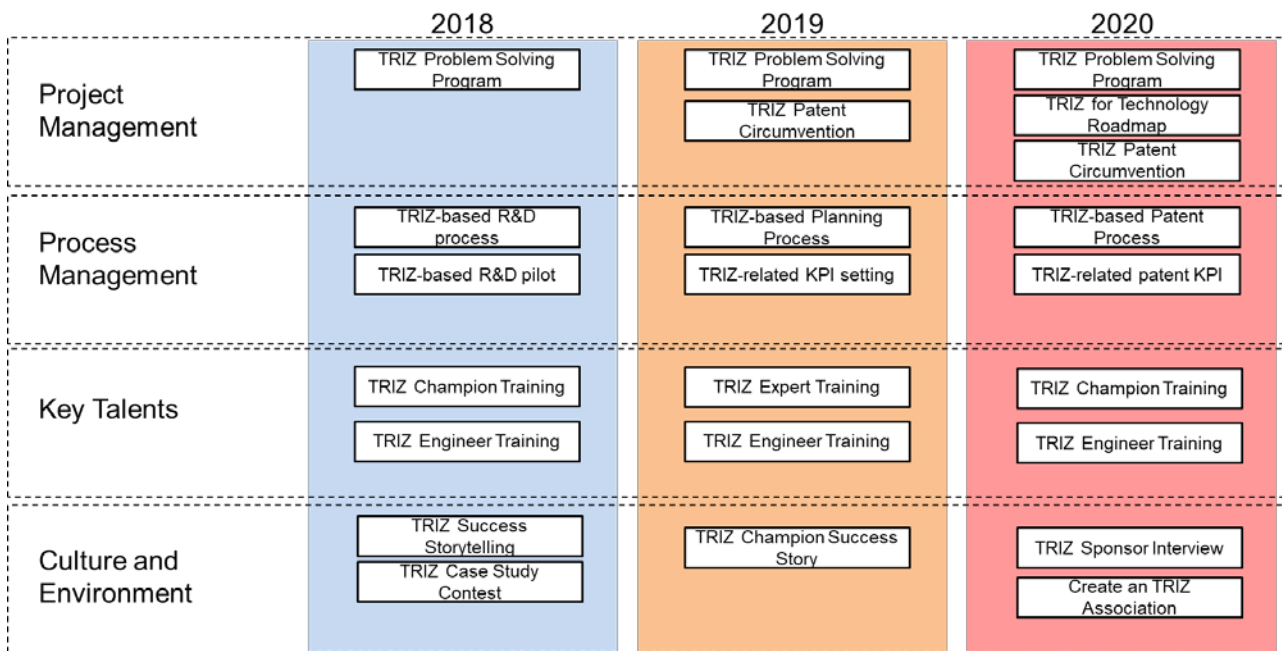


Fig. 10. TRIZ Implementation 3-year roadmap

## 7. Conclusions.

TRIZ is a very useful tool for R&D organizations. However, it is not easy to promote TRIZ successfully. The author studied individual perspective and organizational perspective of this issue, and pointed out that the empowerment process is the crucial part of TRIZ implementation. We suggest that when we empower engineers, we should help them to gain capability, process and results at the same time. From the organization perspective, the author suggested an TRIZ organization model, and roadmap for future TRIZ implementation.

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**Communicating Author:** [arthur.lok@innoenterprise.com](mailto:arthur.lok@innoenterprise.com)

## **TRIZfest 2018**

**September 13-15, 2018. Lisbon, Portugal**

# **RESEARCH ON SEISMIC STRUCTURE OF HIGH PIER RAILWAY BRIDGE BASED ON TRIZ**

Hu Lianjun, Yang Jizhong, Wei Yongxing, Zheng Xiaoyan, Yuan Zhigang

*China Railway Eryuan Engineering Group Co. Ltd, Chengdu, Sichuan 610031, China*

### **Abstract**

With the rapid development of China's high speed railway, thousands of large-span and high-pier bridges have been built in Southwest China, where many strong earthquakes have occurred. It is significant to carry out the research on seismic structure of high pier railway bridge. It could be solved by adopting TRIZ theory and CAI (Computer Aided Innovation) software. According to the bridge structure and the influence of the earthquake on the bridge, seismic function model was built in Goldfire Innovator. On the basis of the flow analysis method, a new dynamic vibration absorbing bridge structure was presented, in which an additional mass was designed as a TMD (Tuned Mass Damper) attached on the high pier. It was like adding an inverted flow to the model. By the resources analysis, the girder acted as the additional mass, which could greatly reduce the seismic energy. Based on the finite element method, seismic behavior of high pier railway bridge and the train running safety subjected to 2 measured seismic waves were analyzed. The results showed that the lateral displacement and acceleration of the pier top could be effectively suppressed, as well as the lateral vibration of the girder. Thus, the running safety of the train was also improved.

Keywords: TRIZ, flow analysis method, resources analysis, dynamic vibration absorbing bridge, high pier

### **1. Introduction**

In order to improve China's railway network, more and more new railways will be built, especially in Southwest China. Due to the existence of numerous great mountains and deep valleys, a large number of large-span and high-pier bridges will be used in design and construction. Moreover, lots of railways cross the collision zone of the Indian Plate and the Eurasian Plate, and also traverse many fault zones, where many strong earthquakes have occurred. Take Sichuan-Tibet Railway in Southwest China for example, it locates in large earthquake zones. According to the related investigations [1], in the Lhasa-Nyingchi Section alone, there are 18 fault zones, leading to many earthquakes in this area in history, including as many as 8 earthquakes with magnitude over 7 and 15 earthquakes with magnitude from 5.5 to 7.0. In the last decade, the largest earthquake occurred in this area is the Wenchuan Earthquake in 2008, whose magnitude is 8.0 [2]. All the data

indicates that the seismic effect cannot be ignored, and special attentions should be paid to vibration reduction of high pier bridges subject to earthquakes in the design phase.

Compared with short pier bridges, the high pier bridges have poorer stability. The stiffness of these bridges is generally small because of the slenderness of the high piers, thus, vibrations of the bridges can be easily excited by external loads such as moving trains, winds, and earthquakes [3]. By now, several studies on high pier bridges have been conducted, however, most of them focused on the optimal parameters of the piers of the dynamics responses of the bridge systems under different of excitations [4][5]. Few works paid attention of the vibration reductions of the high pier bridges [6]. Nevertheless, large earthquakes and high pier bridges are common in Southwest China, thus, more and further research on seismic response control of the high pier bridges should be carried out.

## 2. System Function Analysis

From a designing point of view, any component within a system must have its purpose of existence, which provides function. It could reveal the purposes of the components' and their performances by using functional analysis system technique (FAST), and then discover the roots of the problems. Finally, the problems could be solved with creative design tools [7][8]. Therefore, the function analysis must be established on a certain product. By using functional analysis, we would set up a foundational product functional model for subsequent work.

According to the structure of high pier railway bridge and the impact of the earthquake on the bridge, a function model of the seismic of the bridge is established, as shown in Fig.1.

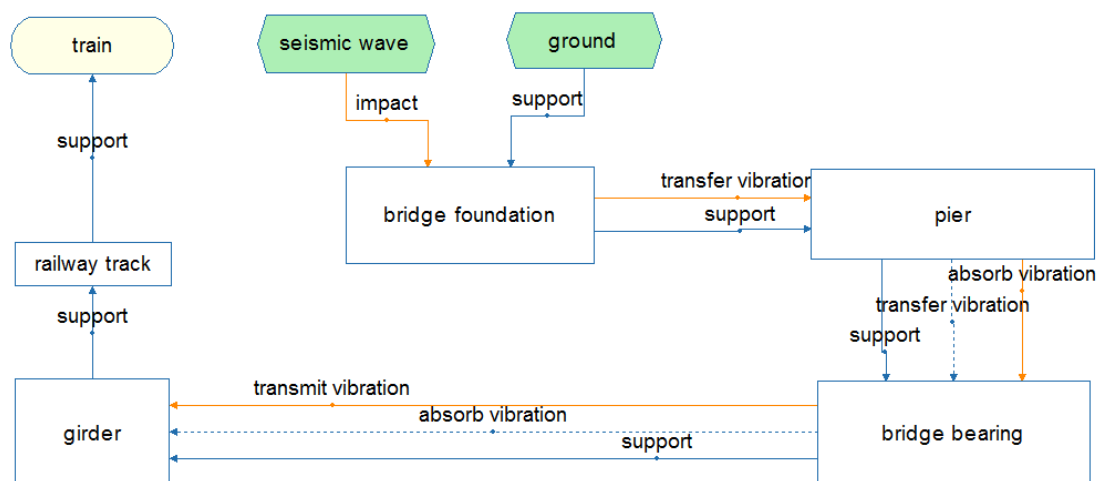


Fig.1 Function model of the seismic of the bridge

The internal components of bridge system include: bridge foundation, pier, bridge bearing, girder, railway track. The external components include: seismic wave, ground and train. In Goldfire Innovator platform [9], the relationships between the various components of the bridge system are shown in Fig.1, where the green polygon frame, white rectangular box with yellow rounded rectangle box, correspond super system, component and target. Yellow arrow and blue arrow represents harmful effect and useful effect respectively. The solid line stands for sufficient effect, while the dashed line stands for insufficient effect.



The functional model diagram shows that, when an earthquake occurs, seismic wave passes through the bridge foundation to pier, and then through the bridge bearing to the girder. Combined with TRIZ theory, bridge foundation, pier, bridge bearing and other components are all in the scope of the seismic structure.

Due to the existence of vibration in every link of the functional model, it is better to adopt flow analysis rather than substance-field analysis. In order to reveal the process of vibration transmission caused by seismic wave, according to modern TRIZ theory, the flow analysis model of railway bridge is established, as shown in Fig.2. Vibration caused by seismic wave passes through the pier to the upper girder, then through the railway track to the train. Although the bridge bearing could eliminate a small part of the vibration energy, most of the energy is transmitted to the railway track and the train, causing great damages. Hence, the vibration energy flow is a harmful flow. In other words, the channel cannot reduce the harmful flow well.

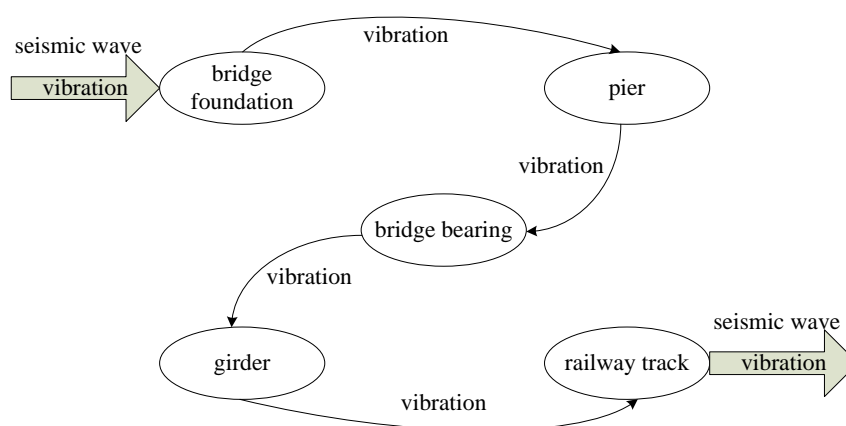


Fig.2 Flow analysis model of railway bridge

On the basis of the flow enhancement rules in the evolution rules of engineering system, there are two sub-trends to reduce the negative effect of the harmful flow: one is to reduce the conductivity of the harmful flow and the other is to reduce the impact of the harmful flow. According to the sub-trend 2, the effect of reducing the harmful flow includes 11 technologies, such as, adding a gray area, redistributing the flow, adding a flow and/or inverted flow, transiting the flow to the super-system, et al.

Based on the above analysis, the flow analysis model is simple and clear, thus, adding an inverted flow to reduce the harmful effect is considered primarily.

### 3. Application of Creative Tool & Generation of Solution

With the flow analysis method, a new dynamic vibration absorbing bridge structure is presented, in which an additional mass is designed as the TMD attached on the high pier. It is like adding an inverted flow to the model.

To design a TMD for a certain primary structure (i.e. high-pier bridge in this work), three key parameters, namely the mass ratio, the stiffness, and the damping, should be determined. Different primary structures have different optimal parameters. Fig.3 shows the standard TMDs attached to

a primary structure with and without a damper, respectively. Whether there is a damper in the concerned primary structure or not directly affects the TMD design [11][12].

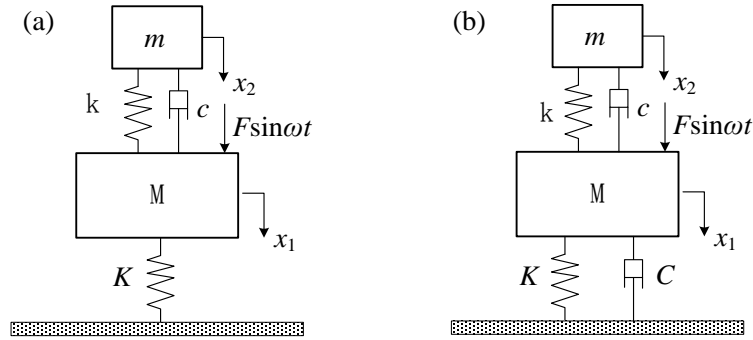


Fig.3 the standard TMDs attached to a primary structure: (a) without a damper (b) with a damper

For the primary structure without a damper shown in Fig.3 (a), the optimal stiffness  $k$  and damping  $c$  of the TMD as expressions of the mass ratio  $\mu$ , which are given as

$$k = m \frac{K}{M} \left( \frac{1}{1 + \mu} \right)^2 \quad (1)$$

$$c = 2m \sqrt{\frac{K}{M}} \sqrt{\frac{3\mu}{8(1 + \mu)^3}} \quad (2)$$

where  $m = \mu M$  (3)

Relatively for the primary structure with a damper displayed in Fig.3 (b), according to the fixed-point theory, the optimal stiffness of the TMDs for this dynamics system can be expressed as

$$k = m \frac{K}{M} \frac{1 - 2Z\zeta(1 + \mu) - 2Z^2}{(1 + \mu)^2 + \mu \frac{Z}{\zeta}} \quad (4)$$

in which  $\Omega_n = \sqrt{\frac{K}{M}}$ ,  $\zeta = \frac{c}{2m\Omega_n}$ ,  $Z = \frac{C}{2M\Omega_n}$  (5)

Note that when  $Z=0$ , Eq. (4) can be simplified to Eq. (1). Also, it can be clearly seen from literature [10] that the maximum magnification factor of the system changes very little even when the damping ratio changes considerably. Therefore, the optimal damping of the TMDs for damped primary structures can also be determined by Eq. (2).

The solution could effectively reduce the vibration of the high pier caused by earthquakes and strong winds through the large displacement vibration of the attached mass. The attached mass is heavier, the mass ratio is greater, and the damping effect is better. However, there is a problem that cannot be ignored. That is the limitation of the installation space and it is impossible to install large mass.

Hence, the functional components of the high pier bridge system are analyzed again, and the available resources are studied [13][14], shown in Fig.4. It is obvious that the girder could be the great mass. The next task is how to turn the girder into the great mass.

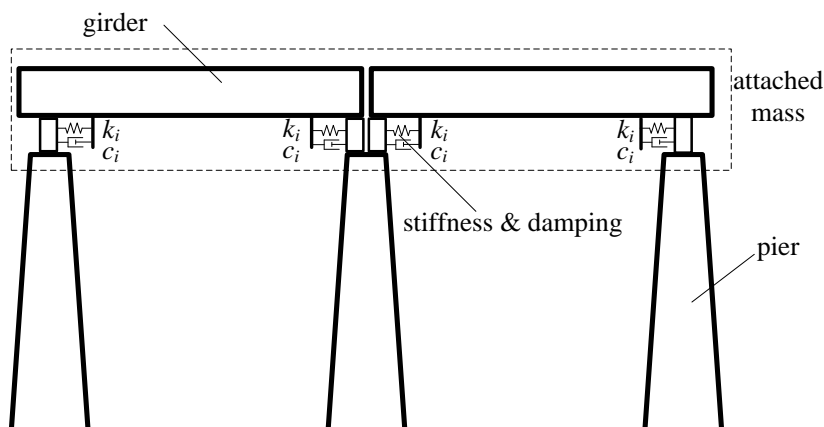


Fig.4 the resources analysis of bridge

With the great mass property of the girder, it can be used as the additional mass of dynamic vibration absorption to improve the seismic performance of the bridge pier. By setting the longitudinal and lateral connection stiffness & damping between the girder and the pier properly, the dynamic vibration absorber attached to the pier is formed. Under the action of earthquakes, the vibration phase of the girder is opposite to the vibration phase of the pier, which could effectively eliminate the harmful vibration of the pier in the frequency band. Ultimately, it could result in reducing the pier stress and improving the seismic performance of the pier.

#### 4. Discussion

According to the solution mentioned above, the girder with large quality is designed a TMD attached on the pier. Based on the finite element method and the train-track- bridge dynamic interaction theory, seismic behavior of railway bridge and the train running safety subjected to 2 measured seismic waves are analyzed, compared with bridge with conventional bearing.

Hence, a detailed finite element model for the primary structure is established according to the actual bridge structures, as shown in Fig.6. It should be pointed out that the 32.6m-long T-beam bridge is widely used in railway. To model different parts of the bridge, different element types are employed. Beam 188 is applied to model girders and piers, while Combin14 is adopted to simulate the behavior of movable supports. Due to the boundary effect, only responses of the middle span bridge are seriously considered. The length of the high pier is set to be 50m, and the secondary dead load is set to be 160kN/m according to the actual weight of the structures including the track and other accessory structures. Moreover, in the following dynamics analysis, the earthquake loadings are considered as global accelerations. According to the equations mentioned above, for the height of the pier is 60m, the optimal stiffness  $k$  of the TMD is  $5.36 \times 10^6 \text{ N/m}$  and the damping  $c$  is  $1.10 \times 10^6 \text{ N} \cdot \text{s/m}$ .

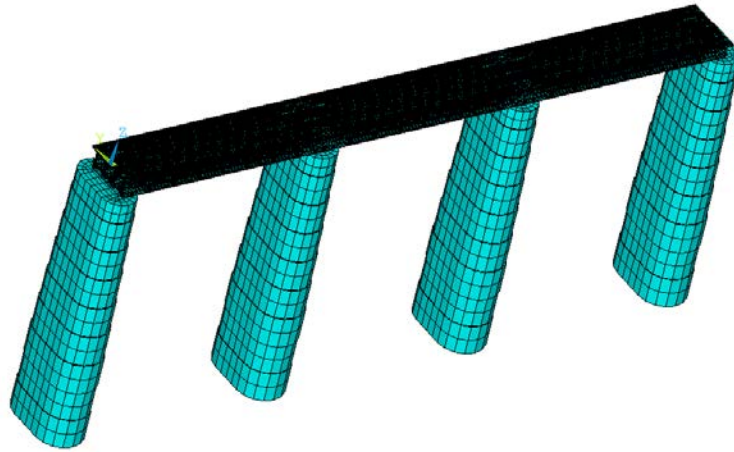
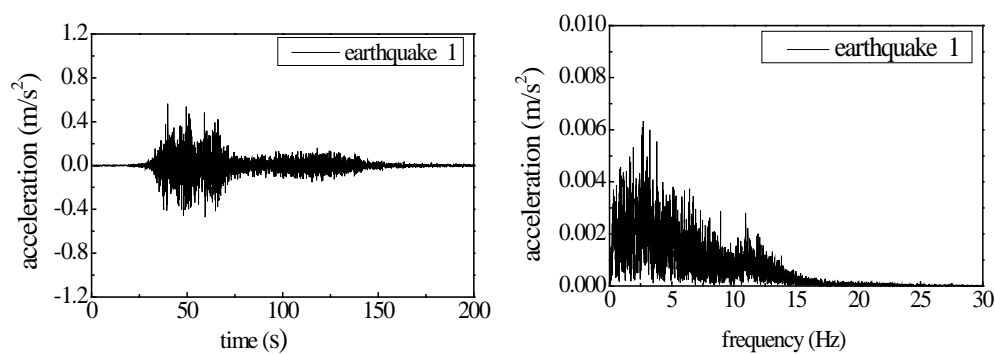
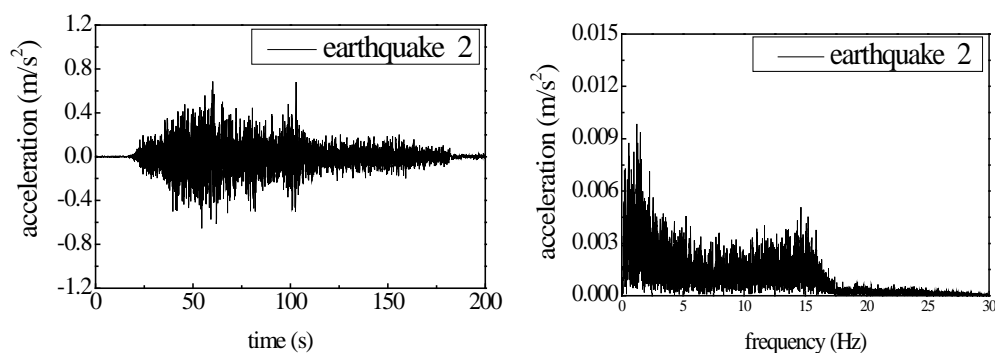


Fig.5 the finite element model of the high pier bridge

To make the calculation results of the dynamics analysis be more approximated to the real condition, 2 different actual earthquake samples of the Wenchuan Earthquake (with magnitude 8.0) happened in 2008 are selected, which are acquired by different seismic monitoring station in Southwest China, as shown in Fig.6.



(a) earthquake 1



(b) earthquake 2

Fig.6 Time history and amplitude frequency curves of seismic wave acceleration

As shown in Fig.7, the lateral displacement of the pier-top is obviously smaller with TMDs than that without TMDs. In Fig.7 (b), it can be clearly seen that the displacement amplitudes at the

frequency of 2.49Hz are significantly decreased to negligible proportions. These results demonstrate that the designed TMDs are effective to reduce the high pier bridge vibrations by suppressing the first bending vibration mode in lateral direction.

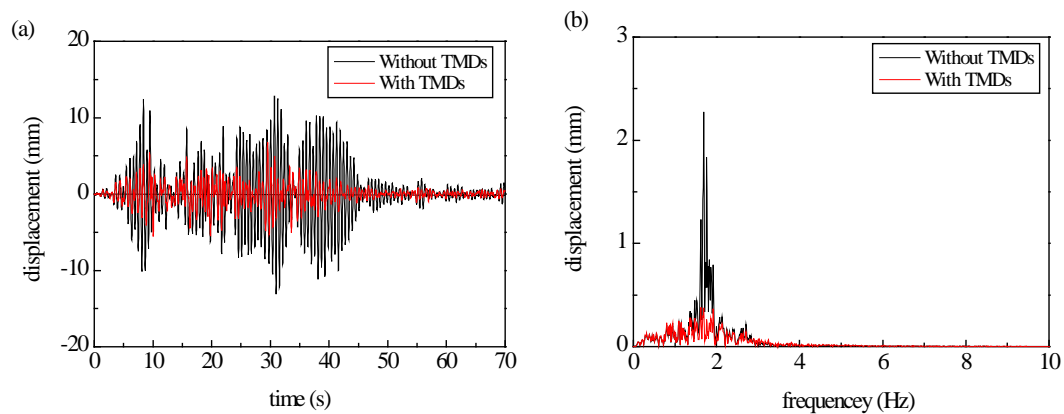


Fig.7 Influence of the designed TMDs on the lateral displacement of the pier-top: (a) in time-domain, (b) in frequency-domain

Besides, the lateral acceleration of the pier-top, and the bending moment and stress of the pier-bottom (the bottom of the pier) are also extracted to illustrate the vibration absorption effects of the TMDs, which are displayed in Fig.8.

It can be seen from Fig.8 that, under different earthquake loadings, all the indices (i.e. displacement, acceleration, bending moment, and stress of the pier) are much smaller with TMDs than that without TMDs. Therefore, it is concluded from the calculated results that the TMD is quite useful to absorb the vibrations of the high pier bridge.

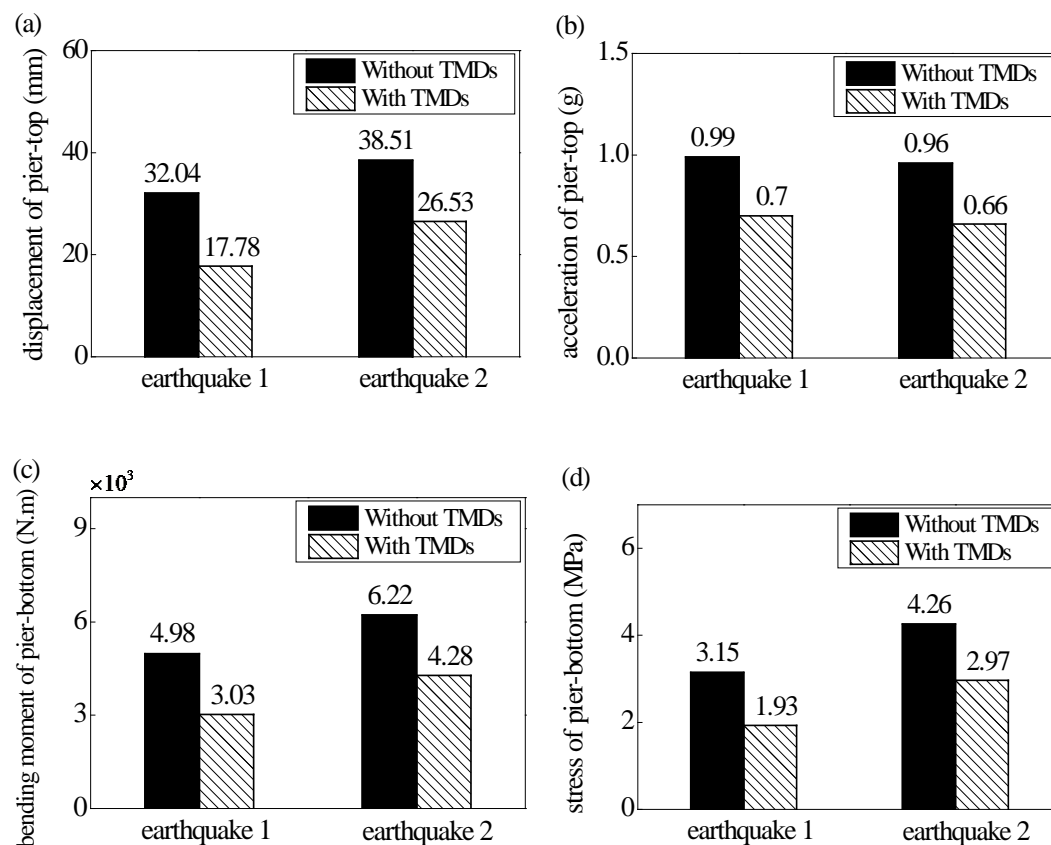


Fig.8 Vibration absorption effect of the designed TMDs subjected to different earthquakes: (a) lateral displacement of the pier-top, (b) lateral acceleration of the pier-top, (c) bending moment of the pier-bottom, (d) stress of the pier-bottom.

## 5. Conclusions

Aiming at practical engineering problem in high pier railway bridge, this paper has adopted TRIZ theory and CAI software. According to the bridge structure, seismic function model has been built. In order to eliminate the influence of vibration, according to the flow analysis method, adding an inverted flow has been adopted. Concretely, an additional mass is designed as a TMD attached on the high pier. By setting the longitudinal and lateral connection stiffness & damping between the girder and the pier properly, the girder acts the additional mass, and the dynamic vibration absorber attached to the pier is formed. Based on the finite element method, with the designed optimal parameters, the attached TMDs are effective to control the seismic responses of the high pier bridge and the running trains. Among the solutions, a patent is applied for a new dynamic vibration absorption bridge structure with the girder is designed as a TMD attached on the pier (application No: CN 106120545 B).

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**Communicating Author:** [hljscu123@163.com](mailto:hljscu123@163.com)

## **TRIZfest 2018**

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# **DESIGN FOR INNOVATIVE HYDRAULIC VALVE STRUCTURE BASED ON TRIZ AND MULTI-ELEMENT COUPLED BIOMIMETIC METHOD**

Zitong Zhao, He Xu<sup>\*</sup>, Haihang Wang, Liye Jiao, Vishwanath Pooneeth

College of Mechanical and Electrical Engineering, Harbin Engineering University,

*Harbin, 150001, China*

### **Abstract**

To improve the anti-cavitation capability of a water hydraulic valve, a multi-element coupling biomimetic modeling method based on TRIZ and the Extenics was presented. A novel valve structure which can change the outlet flow by disturbing fluid was considered based on this method. Firstly, using TRIZ to find biological prototype -cuttlefish and shellfish, a multi-element coupling biomimetic extensive model which simulates the tail drainage hole and groove were established, and the similarity evaluation was investigated, illustrating the quantitative mapping relationship between the biological prototype and the Biomimetic model. Secondly, the CFD instrument was used to simulate the flow condition with some significant parameters obtained. In addition, the CAO software was used to optimize local sizes. Finally, an observing system based on a water hydraulic experiment platform was used to prove the advantages of the new structure.

*Keywords: TRIZ, multi-element coupling biomimetic, flow condition, disturb fluid, groove*

### **1. Introduction**

TRIZ [1] and Multi-element Coupling Bionics (MCB) are two important theories that play an important role in scientific research and innovation. Extenics is an important component of the MCB. This paper proposes a method combining TRIZ and MCB (TMCB), and uses TMCB to improve the common cavitation problem of hydraulic components. Firstly, the TRIZ contradictory matrix was used to find out the principle of improving the cavitation phenomenon. According to the biological resources library, the corresponding examples of cuttlefish and shellfish were found. An Extenics model was established and the prototype was transformed into a hydraulic component. Then, the CFD software was used to simulate and analyze the flow condition [2]. The gas distribution of the normal and TMCB structure was compared. The ISIGHT software was used to optimize the parameters of the innovative structure. Lastly, an observation system consisting of a high-speed camera and a hydraulic control platform was built to make compare the experiments on the relief valve. The formation of cavitation bubbles was quantitatively collected and through comparison, the superiority of TMCB innovation structure was confirmed. The flowchart in Fig. 1 illustrates the main sections of this research.



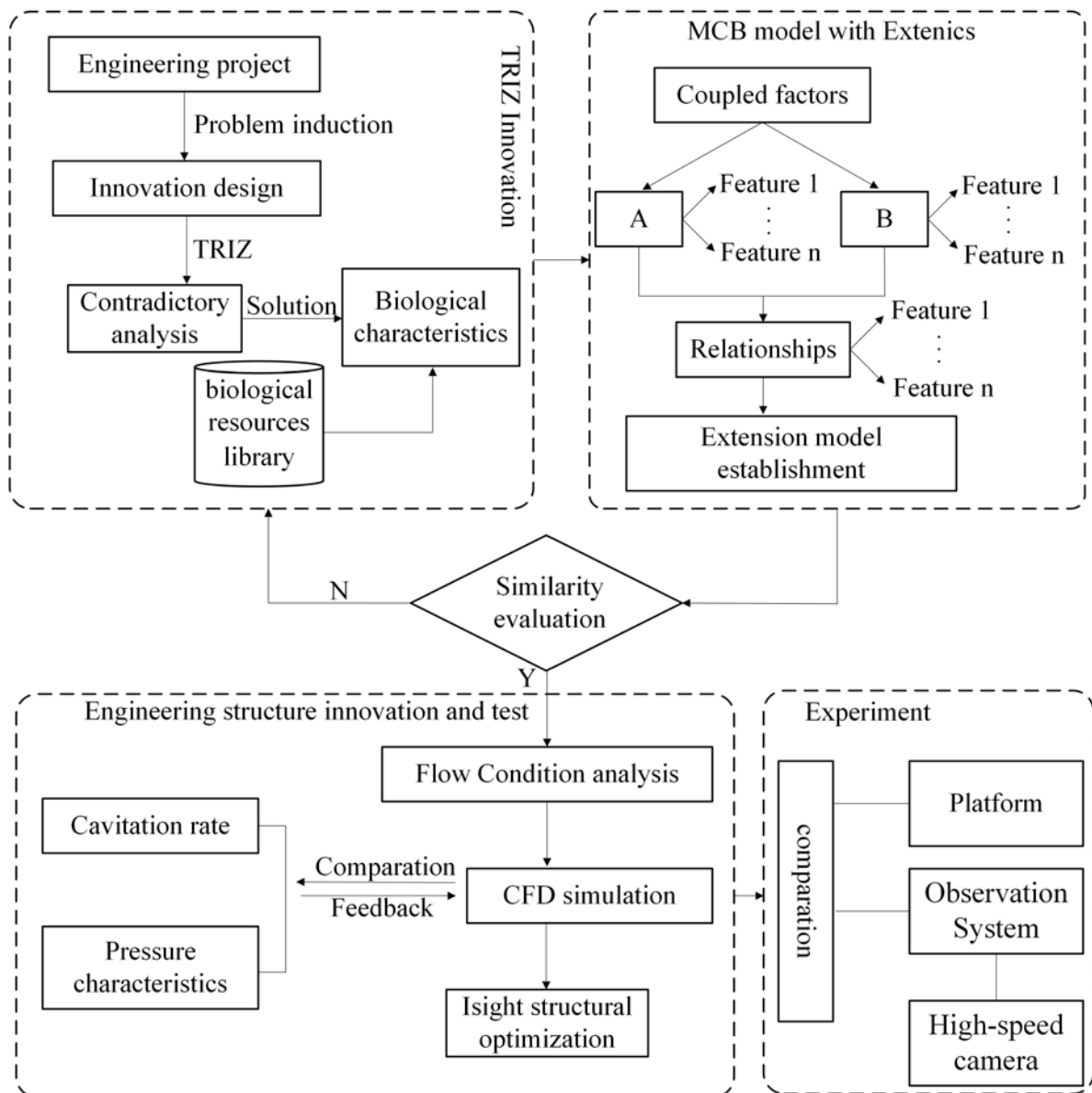


Fig. 1. Flowchart

## 2. TMCB method

TRIZ theory is a concise method, which uses scientific and engineering knowledge to solve technical problems; it is also considered to be a 'smarter' theory [3]. And TRIZ is an innovative design method, The optimized biological characteristics can help designers to obtain the technical system more easily. The combination of engineering issues with bionic is highly convenient in complex problems. The Extenic theory explores the possibility of expanding things and finding innovative methods. Its combination with the TRIZ demonstrates a clear and logical embodiment.. This paper proposes an engineering problem solving method (TMCB) that combines TRIZ with MCB.

## 3. TRIZ application

The fluid flow in the hydraulic valve is often under the conditions of differences pressure with varying flowrates [4]. In the case of relatively small valve opening degrees, with the large pressure difference and the flow rate at the orifice being up to ten cubic meters per second[5], cavitation is more like to occur. The exploding air bubbles cause a lot of noise and bumps, which has a serious impact on the valve's performance.

The conflicts are described by using 39 engineering parameters in TRIZ. The main purpose of the improved structure is to reduce the pressure loss and increase the local pressure, and also improve the quality of moving objects, which corresponds to the improved engineering parameters in the TRIZ contradiction matrix. The new problem is the complexity of the structure and the decrease in productivity, which corresponds to the deteriorated engineering parameters in the TRIZ contradiction matrix.

After determining the engineering parameters in the TRIZ contradiction matrix, the TRIZ contradiction matrix is used to find the corresponding invention principle. Table 1 shows the TRIZ special solution given by the TRIZ contradiction matrix. The corresponding invention principles are: No. 3 Local Quality Principle, No. 10 Pre-Operation Principle, No. 18 Vibration Principle, No. 24 Intermediary Principle, No.26 copying principle, No.28 mechanical system replacement principle, No.30 flexible shell or film principle, No.34 abandonment or repair principle, No.35 state or parameter change principle, No.36 phase change principle, No. 37 thermal expansion principle.

Table 1

TRIZ conflict matrix		
	Equipment complexity	productivity
Moving object quality	26,30,36,34	35,3,34,37
Power	26,35,10,18	3,28,35,37

The TRIZ specific solution is combined with the biological resources library to search for bionic instances. Table 2 is a partial biological example library corresponding to the principle of local quality in the principle of the invention.

Table 2

Biological examples after TRIZ analysis		
Number	Principle of invention	Biological examples
No.3	Partial quality	Deep sea fish adapt to high pressure environment
		The movement of cuttlefish
		The anti-erosion structure of red willow
		Grooved structure of shellfish and dolphin skin

Fig. 2 is the conception of biological characteristics into engineering models. While the cuttlefish swims in the ocean all day, it can perform rapid movements in seawater, especially during the period of hunting. and the maximum burst start-up speed of cuttlefish can reach 20 m/s even more. The cuttlefish physical properties of the velocity are very similar to those of the high-speed fluid at the valve orifice. The resistance of the water flow at the valve port could be reduced on the smooth groove structure of the shellfish, thereby reducing the pressure difference and cavitation .

## 4.MCB Model

### 4.1 Introduction to MCB

MCB is the abbreviation of Multi-element Coupling Bionics. It is an important part of bionics. Unlike traditional unit bionics, multi-element coupling bionics is closer to the actual bionics of biology. It is a new bionic theory which reforms concept ,content and method. It is expected to solve the problem that traditional unit bionics are difficult to solve effectively. Unit bionics refers to the relationship of the functional characteristics just only one factor. However, with the deepening of bionics research, it has been found that the various functions exhibited by biological adaptation are not only one single factor, but also the result of interdependence and interaction of multiple factors through appropriate mechanisms. As for TMCB, it refers to a research method, that is, the combination of TRIZ and MCB.

## 4.2 Conjugate analysis

According to the principle of conjugate analysis, everything has a conjugate part, and the sum of each pair conjugates and their intermediaries is equal to the original, that is, if something is  $O_m$ , then :

$$O_m = sf(O_m) \oplus hr(O_m) \oplus mid_{sf-hr}(O_m) \quad .(1)$$

Where  $sf(O_m)$ 、 $hr(O_m)$ 、 $mid_{sf-hr}(O_m)$  are the 'soft' department, the 'hard' department, and the intermediaries between 'soft' and 'hard'. For the structural research of Multi-element coupling biological prototype, it is possible to perform a 'soft'and 'hard'analysis from a systematic perspective.

The actual components that make up the biological prototype are known as 'hard' parts, and the relationship between the components is known as 'soft' department, the extenic conjugate model about fluid Injection System from Cuttlefish Tail is shown in Table 3.

Table 3

The extenic conjugate model of cattlefish and shellfish				
Conjugate part	Component	Description		Characteristic index
'hard'	Drainage hole	form	'funnel'	shape;quantity; position;distribution
		movement	stretch	Movement method; Movement type
	groove	structure	uneven	Shape;size;quantity; position
		movement	none	none
Intermediary	none			
'soft'	The relationship between the drainage hole and groove	Coordinated movement		Overall relationship; Tightness;Permanent degree

In this article, according to the above extenic conjugate model of cattlefish and shellfish, the anti-cavitation system composed of two marine organisms was subjected to extenic conjugate analysis. The details are as follows, see (2) ( $M_{sh}$  and others are the characteristic indexes):

## 4.3 Similarity evaluation

The anti-cavitation system of hydraulic valves composed of two marine organisms with similarities, in terms of morphology, movement, function and working environment. All of them could change the flow conditions and pressure distribution by disturbing the fluid, In addition, both of them worked under the turbulent conditions.

According to the similarity theory and the judgment matrix evaluated by experts, the coefficient of similarity,  $S^C$ , between the anti-cavitation system consisting of the two marine organisms and the anti-cavitation system of the hydraulic valve was 0.69 ,the anti-cavitation system with the two marine organisms could be selected as the bionic prototype of the hydraulic valve anti-cavitation system.

$$O_m^c = \left[ \begin{array}{lll} \text{drainage} & \text{shape} & \text{funnel} \\ \text{hole} & \text{quantity} & 1 \\ & \text{position} & \text{tail} \\ & \text{distribution} & \text{center} \\ \text{movement method} & \text{Coordinated} & \\ \text{movement type} & \text{elastic} & \\ \text{groove} & \text{shape} & \text{bar} \\ & \text{size} & \text{Depth is 1 mm} \\ & \text{quantity} & \text{many} \\ & \text{position} & \text{external} \end{array} \right] \oplus \left[ \begin{array}{ll} \text{Previous item} & \text{drainage hole} \\ \text{Last item} & \text{groove} \\ \text{type} & \text{Affiliation} \\ \text{integral} & \text{complex} \\ \text{tightness} & \text{close} \\ \text{Permanent} & \text{everlasting} \end{array} \right] \quad (2)$$

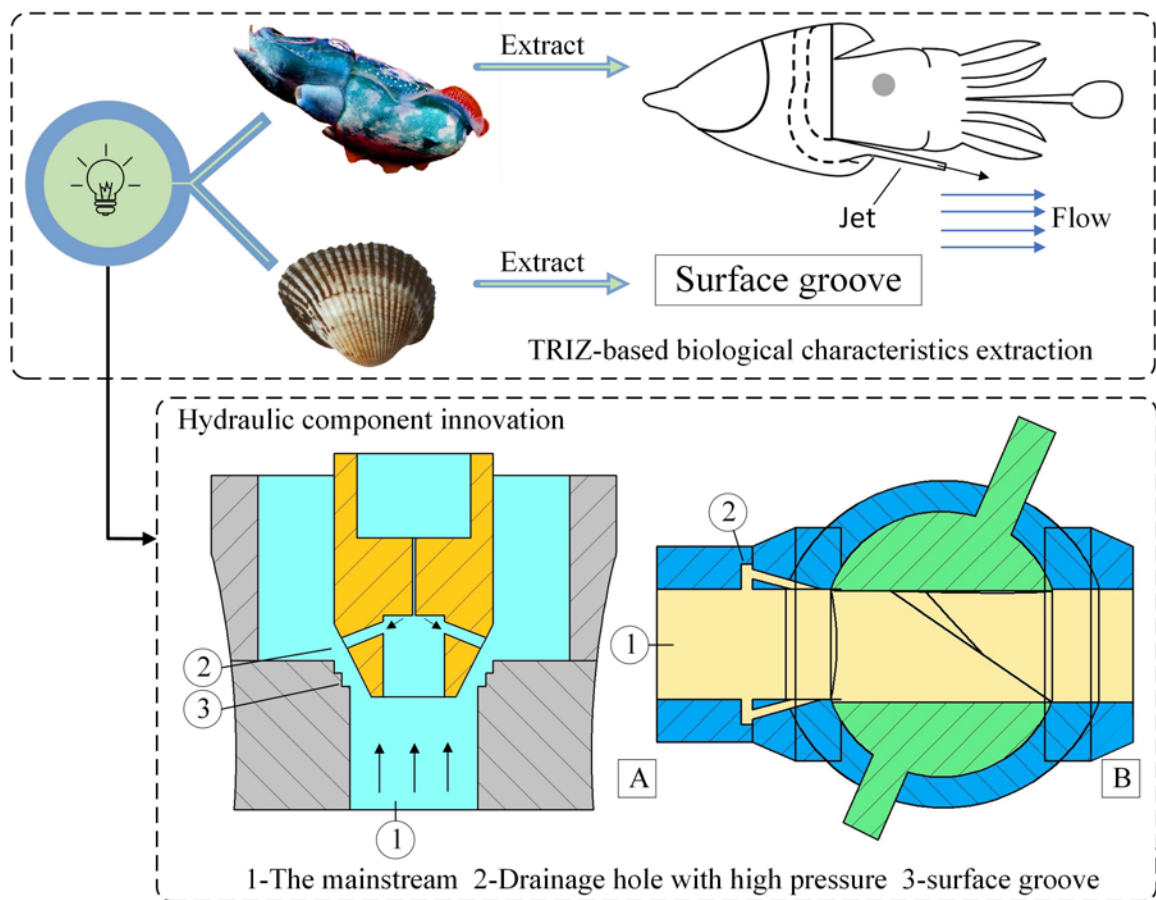


Fig. 2. Correspondence(A is the flow model of relief valve,B is ball valve)

## 5. Transformation and CFD Analysis

CFD, the English full name of Computational Fluid Dynamics, is a branch of fluid mechanics. It uses electronic computers as tools, applies various discrete mathematical methods, conducts numerical experiments, computer simulations and analytical studies on various problems of fluid mechanics to solve various practical problems. This kind of software is iteratively calculated based on the finite element method. The hydraulic valve orifice mainly takes the responsibility of controlling the flow rate, which requires high processing precision and a simple structure. Fig. 3 applies the TMCB model to two typical hydraulic valves. From the results of the CFD [6] multi-phase simulation shown in Fig. 4, it can be seen that either with the relief valve or with the ball control valve, the area where the

cavitation occurs significantly reduced. In the simulation analysis of the relief valve, the area decreased by 37.1%, whereas regarding the ball control valve, it decreased by 14.2%. In addition, the introduction of TMCB also increased the local pressure average of the valve orifice. The introduction of the drainage holes allowed the high-pressure fluid in the front-side of the valve orifice into the rear, which had a good effect in suppressing cavitation.

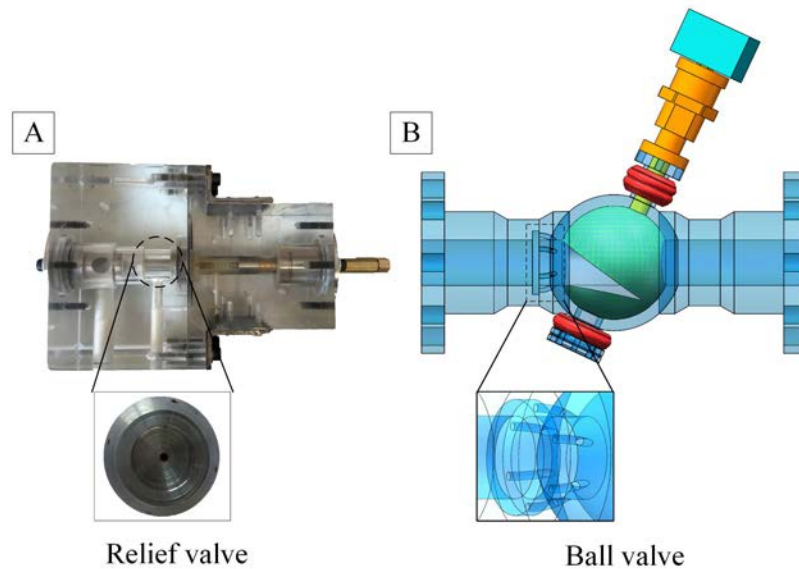


Fig. 3. TMCB to engineering

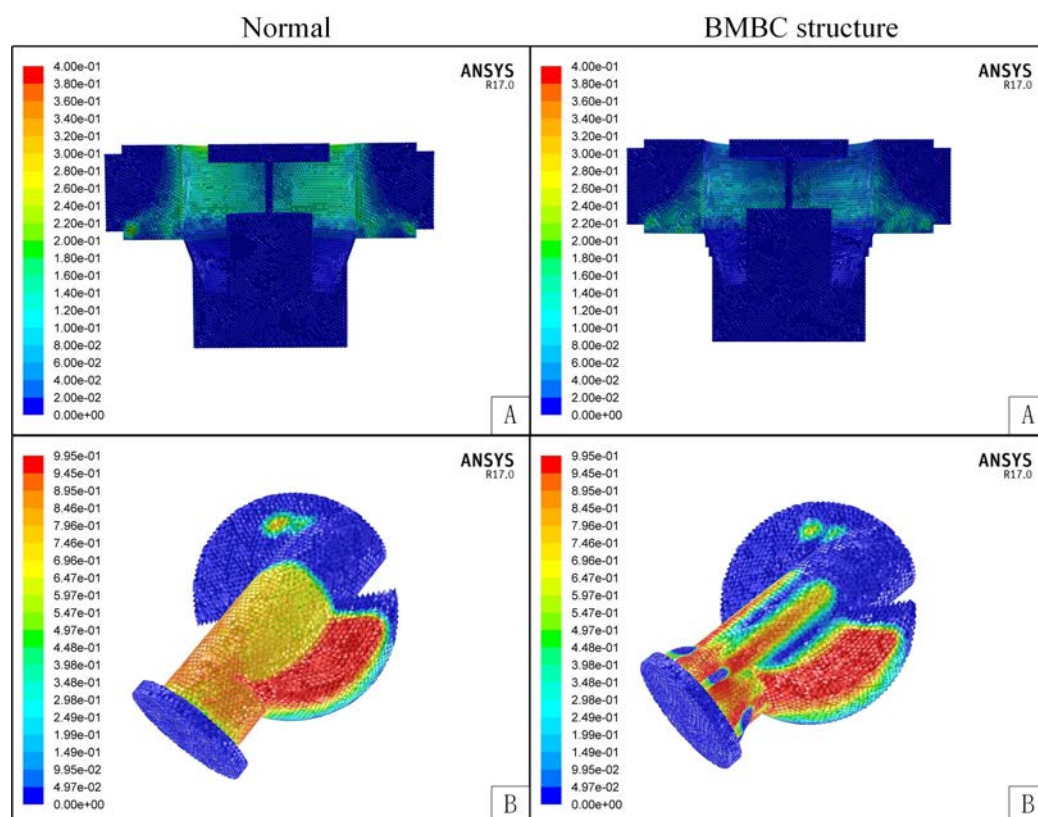


Fig. 4. CFD analysis(A is the flow model of relief valve,B is ball valve)

## 6.Optimization

Isight is a powerful computer-aided optimization design platform with a variety of CAD / CAE and self-programming interfaces, widely used in aerospace and marine automotive electronics and multi-disciplinary design optimization of complex products. Designers can use Isight to integrate cumbersome simulation and modeling software, which is easy to analyze and judge the impact of different parameters on design goals. Using multiple optimization algorithms to automatically analyze and calculate the optimal design, the product development cycle and research cost can be greatly reduced[7].

ISIGHT runs the modeling software and CFD software by starting the batch file with the file format which is 'bat' file. After the calculation is completed, the obtained result data is transferred to the 'Calculator' component that ISIGHT comes with, and then sent to the optimization component for fitness evaluation. This process continues to cycle, and Figure 5 shows the ISIGHT optimization cycle.

In this paper, the diameter of the drainage hole was used as the design variable, and the average pressure in the valve port area is used as the objective function to further optimize the structural parameters. Table 4 and Fig. 6 show the optimization results of valves.

Table 4

Optimization parameters and range(unit:mm)			
Diameter of drainage hole	Initial value	Optimal value	Range
Relief valve	0.4	0.74	[0.4,0.75]
Ball valve	2	1.96	[1.8,2.2]

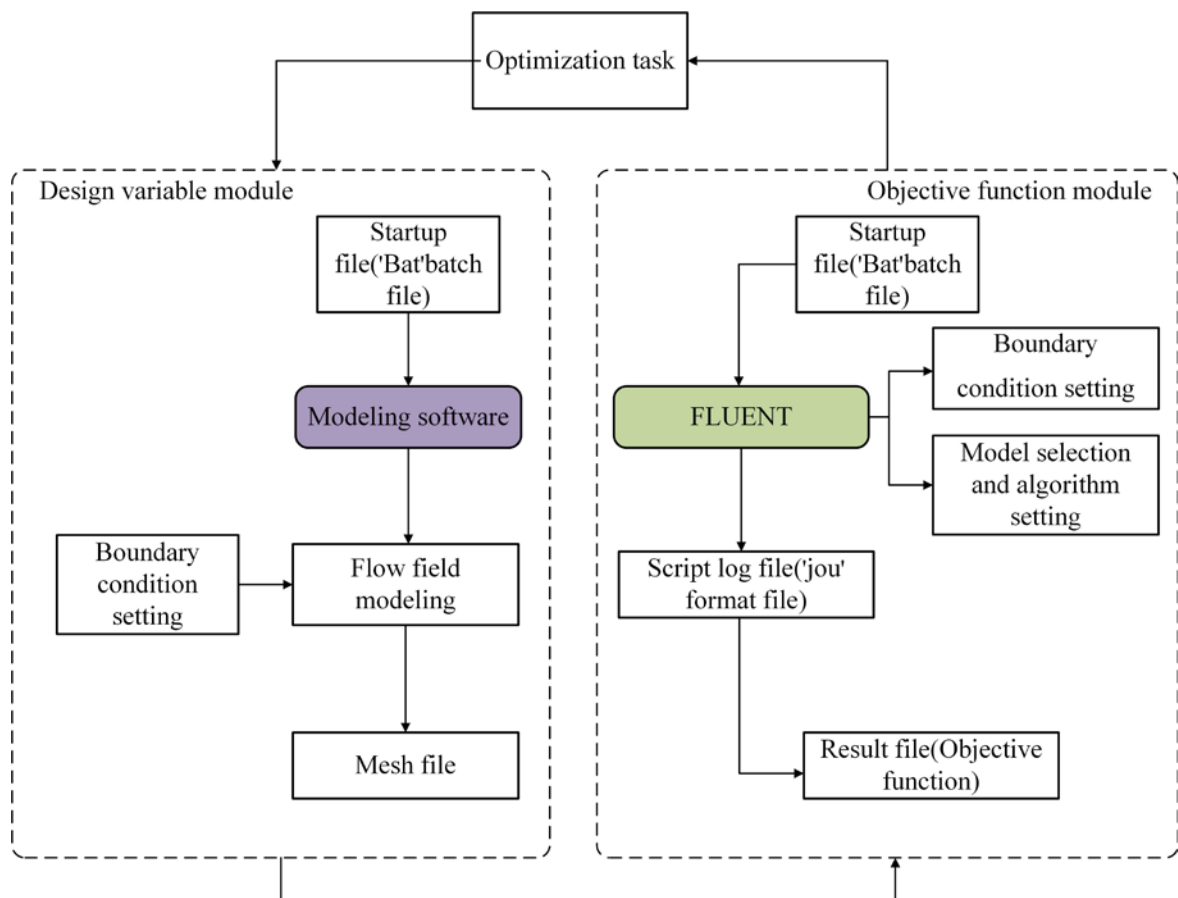


Fig. 5. ISIGHT optimization cycle



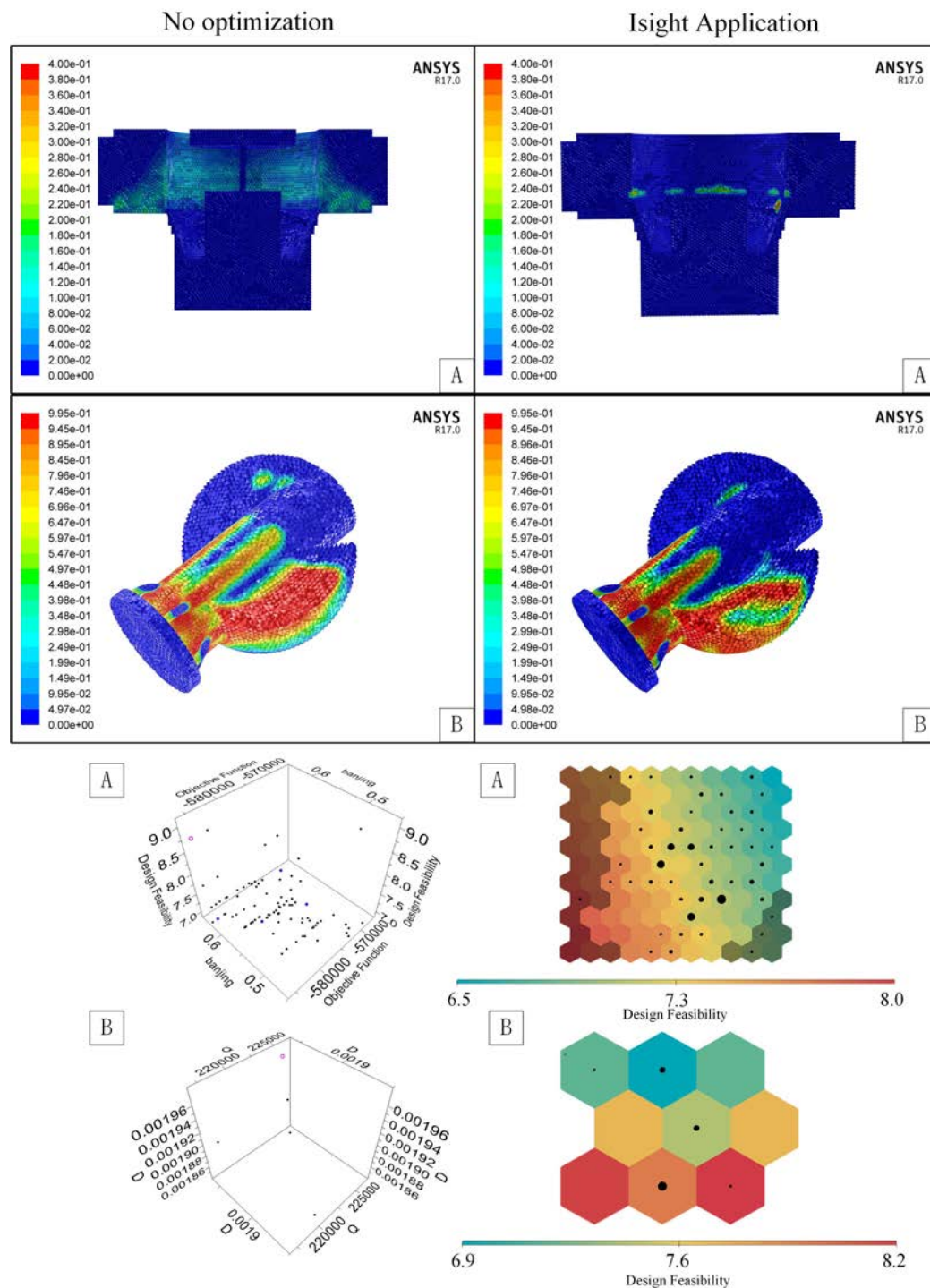


Fig. 6 Details of optimization(A is the flow model of relief valve,B is ball valve)

## 7.Experiment

### 7.1 Platform

Fig. 7 shows the principle of experiment and the observation part. Taking a relief valve as test valve, the cavitation bubbles generated quickly because of the high pressure difference at the orifice, which could only be captured by the high-speed camera. The cavitation images were acquired at the throttle orifice through the control software. According to the needs of experiment, the high-speed camera adjusted the size of the focus area, the shooting rate and the color correction, thus improving the accuracy of experiment. This paper mainly studied the degree of

cavitation in the throttle orifice of different valves. Thus the orifice area was considered and photographed, in order to study the cavitating bubbles.



Fig. 7. Experimental principle and equipment

## 7.2Result

Fig. 8 shows the cavitation bubble occurrences of different structures under the same working conditions. A illustrates the experimental results of the normal structure; B shows the TMCB method and Isight structure optimized model. The degree of cavitation in the normal structure was serious whereas in B, it was reduced. The TMCB method brought a certain improvement effect.

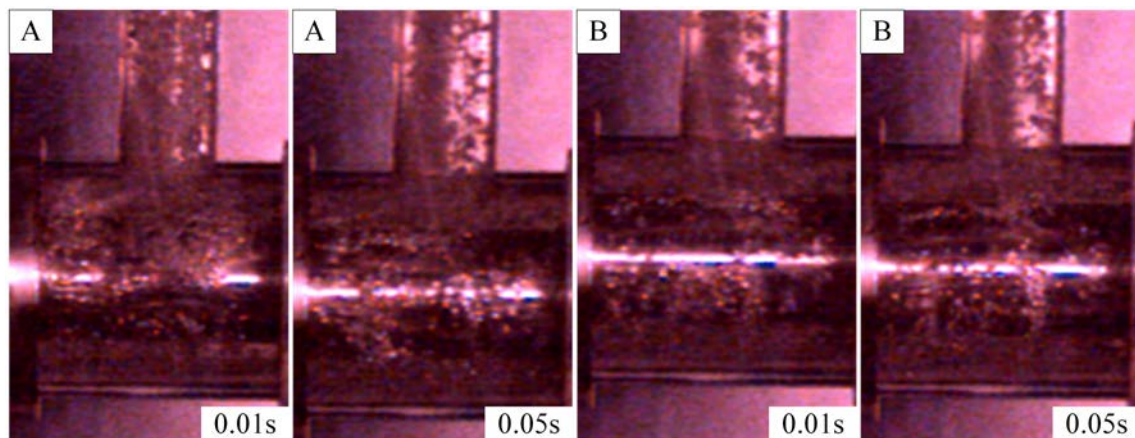


Fig. 8.Result of cavation(Unit: seconds (s))

## 8.Conclusion

This paper studied and analyzed cavitation that is likely to occur in water hydraulic valves. To reduce the cavitation erosion degree, the design concept of TRIZ and MCB was applied. Through experiments, it was found that the occurrence of cavitation in the optimized structure as compared to the original was minimized. thereby proving the effectiveness of TMCB method.

## Acknowledgements



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**Communicating Author He Xu:** railway\_dragon@163.com

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**DESIGN OF FLEXIBLE ARM BASED ON BIOTRIZ AND MULTI-FACTOR COUPLED BIONIC TECHNOLOGY**

Xueshan Zhou, He Xu<sup>\*</sup>, Peng Li, Wanda Zhao, Kundan Sharma, Haihang Wang

*College of Mechanical and Electrical Engineering, Harbin Engineering University,  
Harbin, 150001, China*

**Abstract**

Aiming at studying the relationship between biological prototype and engineering model, a mapping method based on the combination of BioTRIZ and coupled bionics is presented. To make up the disadvantages of the flexible arm, such as poor stiffness, low load/weight ratio, and insufficient driving force, a new structure of the bionic flexible arm with the characteristics of variable stiffness, high load/weight ratio, and jet hybrid driving was designed. Based on the application of the BioTRIZ theory, the two biological prototypes: octopus and squid were found for which the extensive model of multi-factor coupling bionics was built. Then, an extensive analysis hierarchy process was performed to clarify the quantitative mapping between the biological model and the bionic model. In addition, the similarity evaluation between the bionic model and the biological model was carried out. Furthermore, the structural design of the flexible arm was presented and the performance was optimized.

Keywords: BioTRIZ; analysis hierarchy process; variable stiffness; flexible arm; hybrid drive

**1. Introduction**

Bionics and TRIZ theory, as two major innovation methods in the field of natural sciences and engineering, play an important role in scientific research and creative design. Bionics provides new ideas, new principles and new theories for the scientific and technological innovation. However, most of the existing bionic design are bionic of a single organism. Obviously, this can no longer meet some complex engineering design requirements.

Theory of Inventive Problem Solving (TRIZ) was summed up by Soviet scientist G.S. Altshuller and his colleagues analysing a large number of patents and innovation cases. It is one of the important methods to solve engineering problems. Julian F.V. Vincent et al. [1] combined TRIZ with bionics and used TRIZ theory to make full use of the advantages of historical design cases and experiences. He proposed the BioTRIZ theory that supports biomimetic design, which can more clearly reflect the use of biological examples to solve the contradictions of the engineering technology. However, there are the following problems in practical application:

1. Although biological prototypes of biomimetic design can be found through BioTRIZ, for engineering problems, it needs to be introduced into the project through certain means after finding biological examples that can solve the problem. BioTRIZ theory does not give a specific method or step.
2. A corresponding analysis of the similarity between the engineering model and the biological model was not given by BioTRIZ.

In view of the above problems, a modelling method formed by the combination of BioTRIZ and extension theory multi-biological coupling bionics was presented, and the similarity between bio-

logical model and engineering model was analysed. The feasibility of modelling method was proved in the innovative design of rigid and flexible hybrid flexible arm.

## 2. Combination of BioTRIZ and Multi-factor Coupling Bionics

### 2.1 Bionic Instance Search based on BioTRIZ

In order to develop TRIZ as a framework for bionics, Julian F. V. Vincent et al. combined the bionics with the TRIZ theory and proposed the BioTRIZ theory. The introduction of biology into TRIZ does not compromise its ability to solve engineering problems and yet makes it compatible with the natural solutions to various problems from biology. From the perspective of biological function realization, BioTRIZ theory reorganizes and condense the TRIZ technology conflict matrix. The six operational fields of substance, structure, space, time, energy and information are used as the rows and columns of the matrix, and the 40 invention principles are used as the matrix values [1], the BioTRIZ conflict matrix is illustrated as the Table 1. BioTRIZ can be used to access biological strategies for solving engineering problems [2].

Table 1

BioTRIZ Conflict Matrix [1]

Fields	Substance	Structure	Space	Time	Energy	Information
Substance	13,15,17,2 0,31,40	1- 3,15,24,2 6	1,5,13,15 ,31	15,19,27, 29,30	3,6,9,25,3 1,35	3,25,26
Structure	1,10,15,19	1,15,19,2 4,34	10	1,2,4	1,2,4	1,3,4,15,19, 24,25,35
Space	3,14,15,25	2- 5,10,15,1 9	4,5,36,14 ,17	1,19,29	1,3,4,15,1 9	3,15,21,24
Time	1,3,15,20, 25,28	1- 4,6,15,17 ,19	1-4,7,38	2,3,11,20 ,26	3,9,15,20, 22,25	1- 3,10,19,23
Energy	1,3,13,14, 17,25,31	1,3,5,6,2 5,35,36,4 0	1,3,4,15, 25	3,10,23,2 5,35	3,5,9,22,2 5,32,37	1,3,4,15,16, 25
Information	1,6,22	1,3,6,18, 22,24,32, 34,40	3,20,22,2 5,33	2,3,9,17, 22	1,3,6,22,3 2	3,10,16,23,2 5

The process of applying BioTRIZ for bionic innovation design is roughly consistent with the classic TRIZ. The design field problem is translated into a BioTRIZ problem, then the BioTRIZ special solution of the problem is found by applying the BioTRIZ matrix, and the BioTRIZ special solution is the principle of invention in TRIZ. According to BioTRIZ special solution, the matching biological cases are found from the biological instance library based on the principle of invention [1].

The working mechanism of the biological instance library based on the principle of invention is as following, i.e. the past successful biomimetic cases are stored in the instance library in the way of BioTRIZ special solution. In the process of bionic design, the principle of invention given by BioTRIZ special solution is used to retrieve the corresponding biological cases, as the starting point of solving the bionic design problem; If a valid bionic instance is not found through the BioTRIZ special solution, new experience is gained by solving this new problem and then used to

solve similar problems in the future. In this paper, the bionic case library is used based on the TRIZ invention principle established by Yanhui Jian as a bionic instance library [3].

## 2.2 Process of Multi Biological Bionic

Most existing bionic designs are bionic of a single organism. From a single source of biology, this single bionic design is not sufficient to satisfy complex engineering problems. In complex engineering problems, multiple bionic designs are required to solve each different part of the engineering problems and ultimately complete the design of the complex solution.

66% of the cases in the study of Vattam et al. were bionic of multi biological organisms [4]. Therefore, in order to solve engineering problems, multi-biological bionic design will be a trend, in the future. A concept of multi biological bionic is proposed in this paper where we have defined the multi biological bionic design as solving the overall scheme design by solving the unit bionic design of each different part of the overall scheme. The process model of multi biological bionic was presented by analogy with Vattam et al. [4]. In this process, complicated engineering problems need to be divided into separate parts to perform bionic design separately. When a complex engineering problem is presented, the designer decomposes the problem into sub-problems through iterations to obtain an abstract hierarchical structure. As a result, each sub-problem finds a biological prototype through BioTRIZ. The current sub-problems are solved by bionic modelling, and the solutions to the different sub-problems are integrated to generate an overall solution.

Through the research of bionic modelling method, a multi-factor coupling bionics modelling method combining BioTRIZ, multi biological bionic and extension theory was presented. The modelling process is shown in Figure 1.

## 3 Flexible Arm Designs

### 3.1 Flexible Arm Biological Prototype Analysis

The aim is to design a flexible arm which can be bent with sufficient load capacity. Moreover, we need it to reach a wider space in a short time. Therefore, the space position and efficiency were determined as a pair of technical contradictions. The characteristic to be improved is the spatial position, the degraded characteristic is efficiency, “space” and “efficiency” correspond to the “space” and “time” operating domains in BioTRIZ, respectively, so this design problem can be expressed as a BioTRIZ conflict: improving space and worsening time. The special solution of the invention principle can be found by looking for the BioTRIZ contradictory matrix, as shown in Table 2.

Table 2

BioTRIZ Special Solution	
Fields	Time
Space	1,19,29

Using BioTRIZ's invention principle special solution combined with the biological instance library for bionic case search, this article uses the biological instance database [3] created by Yanhui Jian of National Cheng Kung University in Taiwan to search for biological examples. Through comparative analysis, the corresponding biological octopus tentacles of innovation principle 29 was selected as a reference creature of flexible arm design. The corresponding biological cases of innovation principle 29 are shown in table 3.

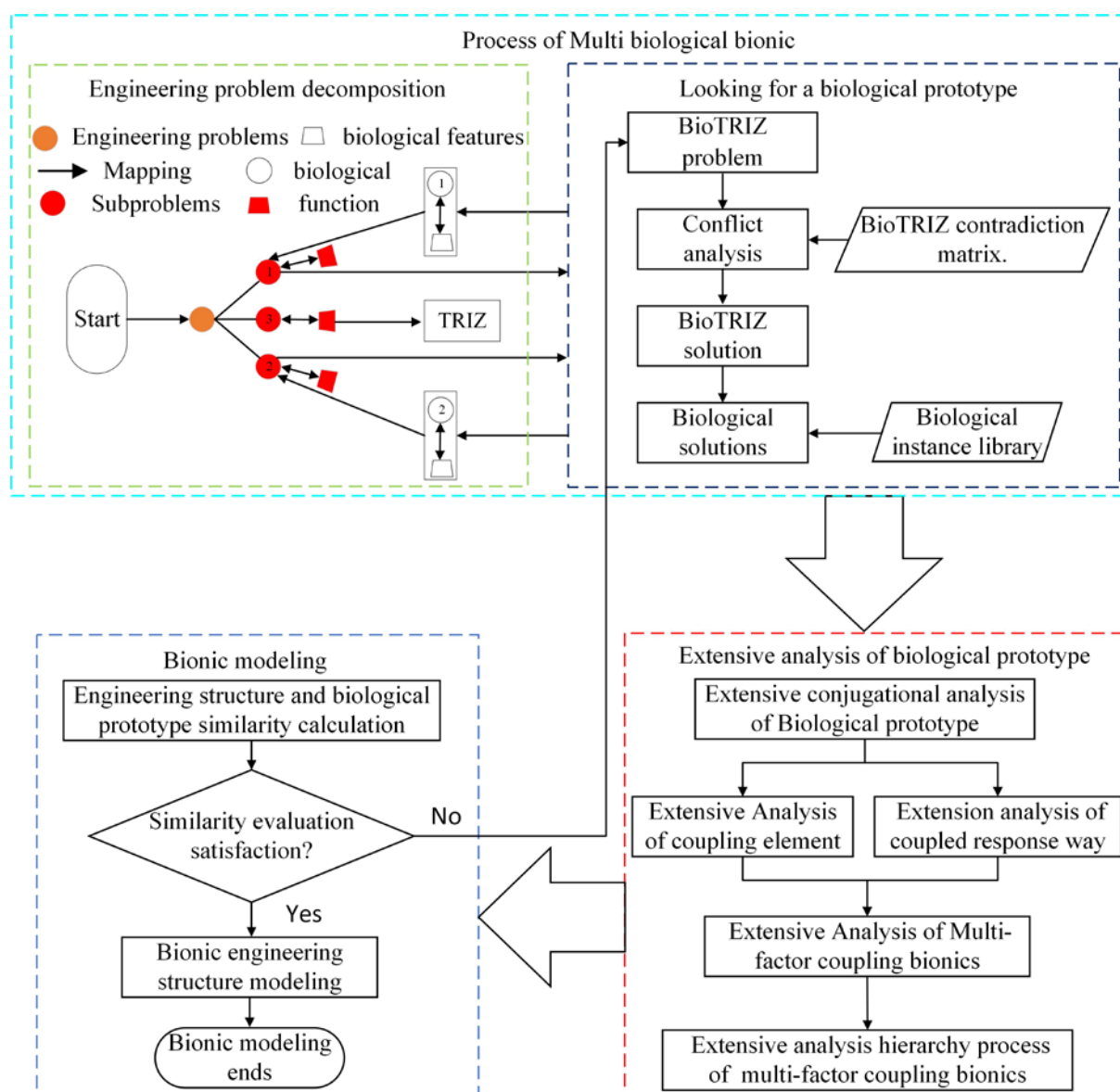


Fig. 1. Bionic modelling method based on BioTRIZ and extension theory

Table 3

Inventive Principle of No.29 Corresponding Biological Cases

Number	Inventive principle	Biological examples
No.29	Pneumatic and hydraulic structure principle	Invertebrates rely on simple but efficient hydrostatic skeleton to maintain body shape and exercise, such as octopuses. Elephant sucks water into long nose and pours water into mouth. .....

### 3.2 Extensive Analysis of Multi-factor Coupling Bionics for Octopus Tentacle

In recent years, some scholars [5, 6] have combined the extension theory, the conjugate theory and the multi-factor coupling bionics principle to propose extensive model of multi-factor coupling bionics, which provides a formalized model for the expression of the systematized information and knowledge of bio-coupling.

According to the conjugate analysis theory, the octopus biological prototype extension conjugate model can be obtained as follows:

$$\begin{aligned}
 M &= \begin{bmatrix} \text{longitudinal muscle} & \text{shape} & \text{ellipse} \\ & \text{size} & 32.5\text{cm} \\ & \text{distribution} & \text{evenly distributed} \end{bmatrix} \\
 \oplus & \begin{bmatrix} \text{transverse muscle} & \text{shape} & \text{four pointed star} \\ & \text{size} & 32.5\text{cm} \\ & \text{distribution} & \text{radiation distribution} \end{bmatrix} \\
 \oplus & \begin{bmatrix} \text{longitudinal and transverse muscle relationships} & \text{previous item} & \text{longitudinal muscle} \\ & \text{next item} & \text{transverse muscle} \\ & \text{relationships} & \text{intertwined} \end{bmatrix}
 \end{aligned}$$

The morphology, structure, and material of the octopus tentacle were selected as the coupling elements, and the octopus tentacle coupling element extension model was as follows:

$$\begin{aligned}
 M_1 &= \begin{bmatrix} \text{morphology} & \text{shape} & \text{approximate cylindrical} \\ & \text{size} & \begin{bmatrix} 3.5\text{cm in diameter} \\ 30\text{cm long} \end{bmatrix} \end{bmatrix} \\
 M_2 &= \begin{bmatrix} \text{structure} & \text{type} & \text{equal volume} \\ & \text{composition} & \begin{bmatrix} \text{longitudinal muscle} \\ \text{transverse muscle} \end{bmatrix} \\ & \text{size} & 32.5\text{cm long} \end{bmatrix} \\
 M_3 &= \begin{bmatrix} \text{material} & \text{characteristic} & \text{soft, flexible} \\ & \text{tissue} & \begin{bmatrix} \text{muscle tissue} \\ \text{connective tissue} \end{bmatrix} \\ & \text{ingredient} & \text{bioprotein} \end{bmatrix}
 \end{aligned}$$

The extension model of coupled response way for octopus tentacles' morphology, structure and material coupling element was as follows:

$$\begin{aligned}
 R_{12} &= \begin{bmatrix} \text{coupled response way} & \text{previous item} & M_1 \\ & \text{next item} & M_2 \\ & \text{relationship type} & \text{affiliation} \\ & \text{extent} & \text{close} \\ & \text{permanent} & \text{permanent} \end{bmatrix} \\
 R_{23} &= \begin{bmatrix} \text{coupled response way} & \text{previous item} & M_2 \\ & \text{next item} & M_3 \\ & \text{manner} & \text{combination} \\ & \text{extent} & \text{close} \end{bmatrix}
 \end{aligned}$$

$$R_{13} = \begin{bmatrix} \text{coupled response way} & \text{previous item} & M_1 \\ & \text{next item} & M_3 \\ & \text{manner} & \text{compound} \\ & \text{permanent degree} & \text{permanent} \end{bmatrix}$$

From the bio-coupling function, coupled response way, and the extensive model based on the above-mentioned coupling element and coupled response way, the extensive model of multi-factor coupling was established as follows:

$$B = \begin{bmatrix} \text{biological coupling} & \text{function} & \text{flexible structure} \\ & \text{coupling element} & M_1 \wedge M_2 \wedge M_3 \\ & \text{coupled response way} & R_{12} \oplus R_{23} \oplus R_{13} \\ & \text{working environment} & \text{underwater} \end{bmatrix}$$

Extensive analysis hierarchy process of multi-factor coupling bionics is carried out as follows: Combining the functional goals of the octopus tentacle, the structural, morphology, and material coupling elements of the octopus tentacle are denoted as  $O_1, O_2, O_3$ . The experts compared them and gave scores to obtain the extension interval number judgment matrix for the function of the coupling layer, and then the synthesis extension judgment matrix can be obtained according to the formula:

$$M = \begin{bmatrix} [1,1] & [2.37, 2.94] & [3.71, 4.96] \\ [0.38, 0.47] & [1,1] & [2.32, 3.02] \\ [0.21, 0.29] & [0.35, 0.53] & [1,1] \end{bmatrix}$$

$$M^- = \begin{bmatrix} 1 & 2.37 & 3.71 \\ 0.38 & 1 & 2.32 \\ 0.21 & 0.35 & 1 \end{bmatrix} \quad M^+ = \begin{bmatrix} 1 & 2.94 & 4.96 \\ 0.47 & 1 & 3.02 \\ 0.29 & 0.53 & 1 \end{bmatrix}$$

As calculated:

$$x^- = [0.6, 0.28, 0.12]^T \quad x^+ = [0.59, 0.28, 0.13]^T \quad k = 0.95, \quad m = 1.02$$

Thus, there are:

$$S_1^b = [0.57, 0.602], \quad S_2^b = [0.266, 0.2856], \quad S_3^b = [0.114, 0.1326]$$

$$P_1^b = V(S_1 \geq S_2), \quad P_2^b = (S_2 \geq S_3), \quad P_3^b = 1$$

Through normalization, the weight vector of each coupling element's impact on the functional target is:

$$P = [0.66, 0.306, 0.034]^T$$

It can be seen that the contribution of structural, morphology, and material coupling elements were: 0.66, 0.306, and 0.034, respectively. So that the structural coupling element was the primary coupling element, the morphological coupling element was the secondary primary coupling element, and the material coupling element was the general coupling element.

### 3.3 Similarity Evaluation between Bionic Model and Biological Model

The similarity between the tentacle and the design target was calculated, and the evaluation factor set for the weight coefficient is given as :

$$U = [u_1, u_2, u_3] = [structure, function, shape]$$

According to the evaluation factors, check the scale [7] to obtain the judgment matrix  $M$  as:

$$M = \begin{bmatrix} 1 & 2 & 3 \\ 1/2 & 1 & 2 \\ 1/3 & 1/2 & 1 \end{bmatrix}$$

From the above formula, we have obtained  $W = [0.8468, 0.4460, 0.2565]^T$ ,  $\lambda_{\max} = 3.0092$ , where  $CI$  is available according to the following formula:  $CI = (\lambda_{\max} - n) / (n - 1) = 0.0046$ .

According to the RI table,  $RI = 0.5149$ , from the formula  $CR = CI / RI$ , we can get the consistency ratio as  $CR = 0.0089 < 0.1$

The similarity coupling between the octopus tentacle and the design object was:  $q = (0.55, 0.65, 0.4)$ . The similarity between the biological prototype octopus tentacle and the design target can be calculated as:  $Q = 0.8468 \times 0.55 + 0.4460 \times 0.65 + 0.2565 \times 0.4 = 0.87$ . According to the similarity evaluation rule, the octopus tentacle can be used as a design prototype of a flexible arm.

### 3.4 Flexible Arm Design

According to the octopus shape, this paper designs a hydraulically driven flexible arm, as shown in Figure. 2. A, B, and C are high-elasticity flexible hoses. The three hoses are evenly distributed at  $120^\circ$ . When these three hoses are fed into water at different pressures, the flexible arm will bend.

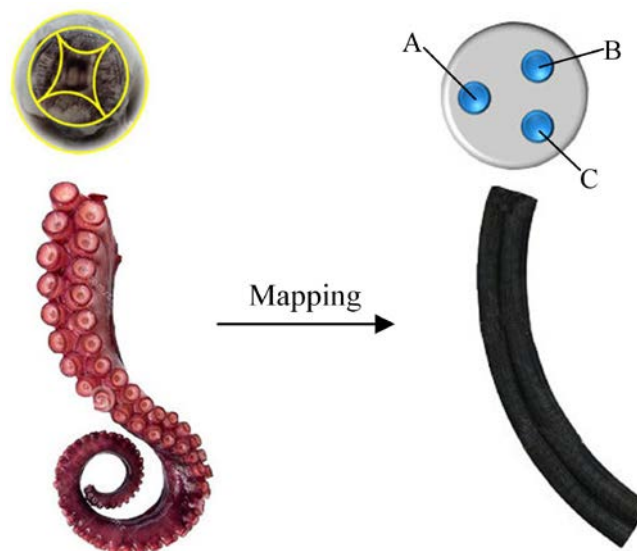


Fig. 2. Flexible arm

However, it has been found through experiments that the driving force of the flexible arm was insufficient and the flexible arm needs to be improved. We need to increase the driving force but the structure should be simple. Therefore, the driving force and structure were determined as a pair of technical contradictions. The 'driving force' and the structure correspond to 'energy' and 'structure' in BioTRIZ, respectively, then the design problem can be expressed as a BioTRIZ conflict:



improving energy and deteriorating the structure. The special solution of the invention principle can be found by searching the BioTRIZ contradictory matrix, as shown in Table 4.

Table 4

BioTRIZ Special Solution

Fields	Structure
Energy	1,3,5,6,25,65,36,40

Using BioTRIZ's invention principle special solution combined with the biological instance library for bionic case search, this article uses the biological instance database [3] created by Yan-hui Jian of National Cheng Kung University in Taiwan to search for biological examples. Table 5 is a partial example library corresponding to the principle of partial quality in the principle of the invention.

Table 5

Part of the Biological Example Library Corresponding to the Principle of Partial Quality

Number	Inventive principle	Biological examples
No.29	Partial quality	<p>Deep sea fish adapt to underwater high-pressure environment.</p> <p>Squids are able to propel themselves by jetting water with high jet thrust.</p> <p>Bionic red willow has anti-erosion structures.</p> <p>.....</p>

Through the analysis we learned that the squid can rely on the nozzle to produce a relatively large jet thrust. According to the characteristics of the squid, we initially made the squid nozzle structure as a biological prototype. The squid nozzle was identified as a biological prototype through extensive analysis of multi-factor coupling bionics, extensive analysis hierarchy process and similarity evaluation. We designed a nozzle model similar to a squid nozzle at the end of the flexible arm. As shown in Figure 3.

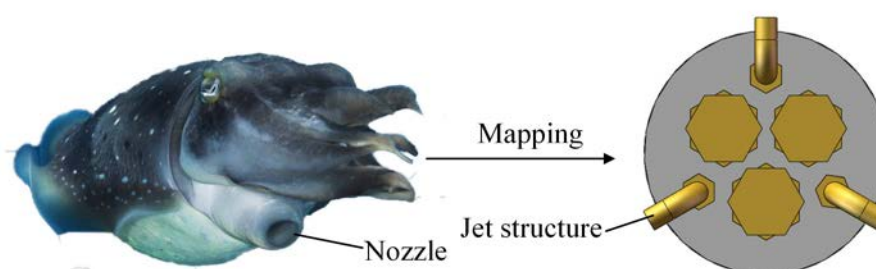


Fig. 3. Flexible arm + Jet structure

### 3.3 Flexible Arm Performance Optimization

The flexible arm was optimized through TRIZ. Because the flexible arm works underwater, we need to reduce the weight of the structure without making the structure's size too small, thereby obtaining a pair of contradictions in the size and weight of the structure. If the structure size of the object was defined as the macroscopic "shape" parameter, then the ability to operate the object in an unknown working environment can be described by "adaptability", and the two as a pair of

technical contradictions. The principle of the invention can be found by looking for the TRIZ contradictory matrix, as shown in Table 6.

Table 6

TRIZ Conflict Matrix

Contradiction	Static object quality	Contradiction	Shape
Static object size	28,35,40,29	Adaptive	1,8,15,37

The inventive principles of No. 8 and No. 35 were chosen through comparative analysis. No.35 refers that the weight of an object or the mass distribution of gases, liquids, solids, etc were changed by changing some of the physical and chemical parameters of the structure, in order to achieve the effect of changing its weight and stress characteristics; No.8 is the principle of weight compensation. It is possible to change the weight ratio of each part of the structure and finally determine the mixing of substances in different phase states to change the overall density of the structure and reduce the weight. We added the solid phase to the liquid phase and selected the density of solid phase to be less than the density of water which as a result it can produce a certain buoyancy in water and provide weight compensation.

The internal cavity in the flexible structure uses the liquid-solid mixed phase as the pressure medium, the solid is sturdier than the liquid and can be regarded as completely incompressible and highly resistant to high pressure. Therefore, if the cavity is filled with material particles in advance, it will not be deformed by external pressure, which ensures that the flexible structure can have a relatively stable form; if the space other than the solid material particles of the flexible structure is completely emptied, the internal particles are closely arranged each other and have certain mutual extrusion ability. Under the balanced state of interaction forces, the internal position of the particles is intentionally fixed, giving the whole flexible structure a certain degree of rigidity.

So far, the design of the flexible arm has been completed, and the final design is shown in Figure 4.

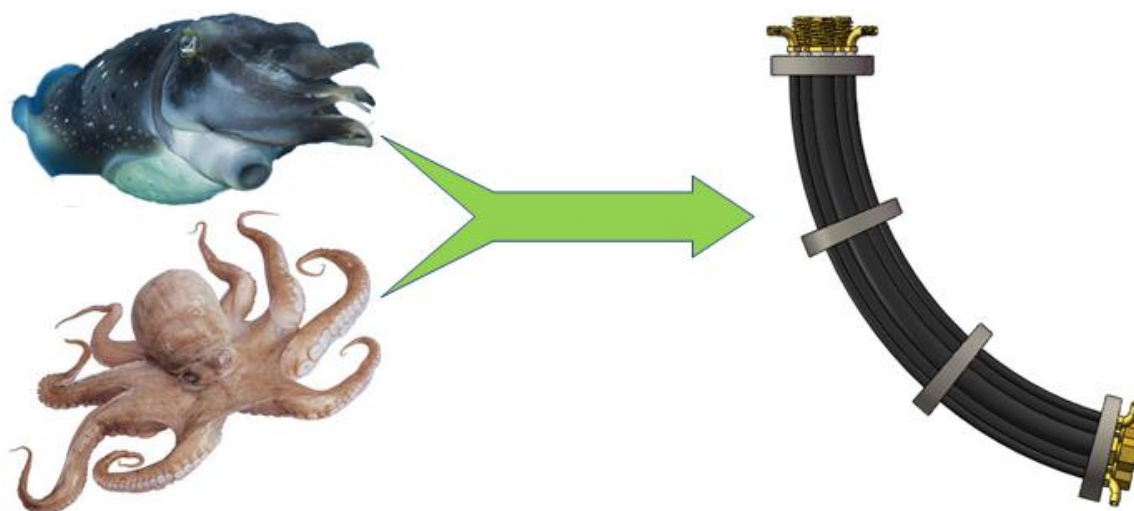


Fig. 4. Flexible arm structure

## 4 Conclusion

BioTRIZ was combined with multi-factor coupling bionics, and the method of multi biological bionic was applied. A new bionic modelling method based on BioTRIZ and extension theory of multi-factor coupling bionics was presented. And the engineering problem was decomposed into several sub-problems. The TRIZ and bionics were applied to solve the sub-problems. In regard to

the bionic part, the biological prototype was searched through BioTRIZ, the extension theory was utilized to analyse the biological prototype, and finally the similarity evaluation was implemented. With respect to the TRIZ part, the solution principle was found through the contradiction matrix. The designed flexible arm using this modelling method has the characteristics of two species of octopus and squid, and uses TRIZ to optimize the performance. The flexible arm has the characteristics of hybrid driving and variable stiffness. The effectiveness of the modelling method was verified.

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**Communicating Author He Xu:** railway\_dragon@163.com

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**FEEDBACK TO INTERMEDIATE STEPS IN PRACTICAL  
SUBSTANCE-FIELD GENERATION**

Michael Schöwel, Glonn, 85625, *Germany*

**Abstract**

First iterations with the TRIZ method “substance field modelling ” (SuF) are often regarded as slow learning phase. A proper problem formulation for further transfer to other TRIZ-tools needs additional effort.

However, first observations of this period at different boundary conditions (industry, high school and elementary school) generate the impression that within the “modelling phase” the number and quality of generated ideas is remarkable high and practical.. In addition, participants seem to learn and understand more by improving models in small steps than from the final model only. As a result, a “hustling through” the SuF-generation process until the model is finally completed is not recommended here as it is not a harmful situation.

This paper shows some feedback from the experienced development of substance field models (SuF). In a small steps analysis approach it tries to link upcoming ideas in the solution finding process within the actual sub-steps and compares this to other fields where similar phenomena seem to appear.

Keywords: *learning by modelling, Substance Field model, SuF, ARIZ*

**1. Actual status**

*1.1. Learnings in TRIZ level 2 and TRIZ level 3 trainings*

In TRIZ Level 2 trainings the students get introduced (latest) to substance field models (SuF) where a technical problem is mostly abstracted to an interaction of two components within a field. Although some exceptions are made (e.g. for measurements problem models that include a second field or third component) this general setting results in a final model that (according to TRIZ) gives also some recommendations for preferred solutions (e.g. standard solutions or inventive principles). When the model itself is not already in complete state, there are several specific hints how to complete it.

In TRIZ Level 3 courses the students learn within the ARIZ algorithm to transfer a complete SuF also to similar forms of TRIZ models (e.g. technical contradiction, physical contradiction, function model). The benefit of this transformation is not just to get a different “view” to the problem but also a slightly different problem formulation. As a model can be already understood as a (simplified) copy of a system this approach also follows the innovative principle IP26 “the usage of copies”. Those models can be used “in parallel” (IP 5 “merging”) from several points of view. This indication of several innovative principles also recommends to use this kind of approach.

*1.2. Further impressions*

Further literature [1] shows that a SuF follows further rules and trends ( simple field, coordination, action, forced field, complex field). The model itself can be extended with other parts (“knowl-

edge”) or components (e.g. measurement SuF) in order to describe the following solution finding processes in even more detail.

### *1.3 Personal experience*

Based on personal experience, some remarkable progress within the solution finding seem to evolve in much smaller and very different steps and seems to be worth a more detailed evaluation. The feedback statement “We made some of our best ideas out of really bad models” from several colleagues in the last TRIZ based workshops reinforces this observed impression. First impressions indicate that within the sorting and TRIZ modelling process the user gets better aware of the real problem and can find a solution (guided and assisted by the algorithm) more easily. By trying to archive intermediate results that even may differ strongly (or even demand the opposite [2]) from the final result participants seem to have less problems to archive a good final result. First specific test for SuF modelling seemed to support this subjective impression, nevertheless the budget in companies for a number of identical tests for the same problem (that shows at least some statistical significance) is limited. It was also expected that this phenomena of intermediate steps had been observed already on other, similar condition.

### *1.4 Comparison to similar effects in other fields*

Compared to this situation of solution finding, the word learning progress of children, which is also a series of different mental efforts, apparently seems to show something similar:

In children education, according to actual standard learning theories acc. Frith [3] and Valtin [4], a word is learned in several steps. By starting from the single graph (visual letter e.g. “a”) the phoneme (the sound here “ə” or “æ”) linkage of single the phonemes (“letters”) culminate in forming a word. Children get the information that each “letter collection” separated with space is a group called “word” and forms a united information (e.g. a subject of a sentence). The letter series itself gives (often only) a first (rough) hint for the correct pronunciation. The following (passive) hearing experience and active speaking and writing exercise in loops prepares the further learning of morphemes (combination of graphs e.g. “pp”) and touch of objects (according the trend of increased addressing of human senses[5]) until (in some stages) even taste (e.g. for “apples” it is also possible) helps to get a better understanding. When this is broadly given and stable, the pupils learn different (species of the “apple”) classification in the next step that allows them to define their expectation to additional parameters (e.g. taste/species, colour, size, vitality/condition, weight, recipe/temperature, toppings ect.) in more detail.

Also the learnings of high school students in modelling a complex relation (like the glucose-insulin regulation) by starting only with partially worked out models show better results than the compared groups. So this approach does not only result in a higher number of loops and activity but also in higher effectivity as it was already shown in a study with around 20 participants [6]. It seems that this extra gaining of experience by own modelling efforts can be also transferred to the modelling of SuF.

## **2. Learnings**

### *2.1. Focus of attention considerations*

At first glance, the interesting point “from outside” here is often where is the most effective learning period within those steps. Transferred to solution finding process the interests are focussed “when” do the “good” ideas occur “most likely” in order to “speed up” the finding process. The final result might be not impacted with an improved intermediate result, but the probability to find final solutions more stable or (even better) to find more solutions seems to be increased. Even by

considering that this additional process needs additional preparation and mandatory pre-steps, some intermediate steps might be so different that they cannot be compared easily or divided in linear sub-steps as it can be already seen in the progress of learning words. This general phenomena of unequal development of steps might also follow an universal trend also in solution finding and understanding (as the problem behind is quite similar) but there are some limitations.

When trying to use a linear “story telling” method like a “pan narrans” [7] in order to describe interacting actions of participants simple systems can become quickly difficult for a proper description. Especially when development happens in intersecting cycles (“breathing” back and forth development on many levels) the focus to the emergent function of the system becomes essential. A storyteller often needs to approximate facts only to a certain level in order to keep the overall story working and understandably. In addition a closer investigation of sub-steps (e.g. stones of a bridge) might not help at all to understand the impact of the system (e.g. bridge) to the environment even when the full system consists only of identical parts (e.g. “stones”) [7] although better subsystems might be constructed with those results. Even the famous “circular thinking” might fail here as some generation process of the result might be not directly visible (e.g. the arc generation of a bridge is not (directly) documented in the resulting stone arrangement, nor the evolutionary development of the bridge construction itself [7]).

TRIZ methods seem to focus on the overall story also for this reason. This “level of granularity” consideration seems very similar to the ASIL decomposition process [8] where specific considerations are requested. This is done in order to check if the problem solving approach is addressed on the “right” level and “proper” detail. This seems to fit better than thinking about “balance equations” or trying to weight sub-steps in relation to effort and result.

At next simple thought, it seems less important to the result which intermediate step can be solved faster or which sub-step has the biggest share on the overall result when sub-steps are not stand-alone solutions. When a following step needs intermediate steps in advance as a precondition this approach of grading and sorting becomes useless unless some recommendations for “asymmetrical” time spending can be given to specific sub-steps due higher “finding” probabilities. But according to ARIZ step 9 [9] it seems worth a try to think also about the parts of the process chain that seems to stop or delay the overall solution finding. There are also some recommendations to check which step prepares or generates (quite fair) stand-alone solution on an arbitrary example of a SuF, even if this shows only relations within a specific niche. The supposed “story constructed afterwards” might also differ not only slightly from the “real” background mechanisms due several bias of setting and participants limits that cannot be removed completely. The result content value itself might be also impacted from further statistical limitations in addition.

## *2.2. ARIZ related approach to an arbitrary SuF's in terms of modeling*

For a general illustration an arbitrary problem without a confidential limitation was chosen for the generation of a SuF (see Fig. 1). The focus here is not to show solutions but (some) assumed relations from the SuF modelling to the ARIZ algorithm, identifying the SuF generation itself also as a modelling algorithm where sub-steps can also provide or prepare sufficient and robust solutions within a sufficient time when built up stepwise.

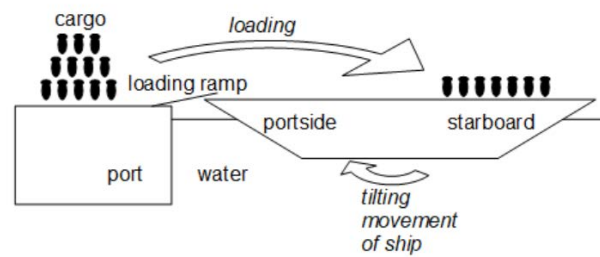


Fig. 1. schematic of an arbitrary ship loading situation

A ship (not completely fixated on a port bollard) shows a strong and unwanted tilting (to starboard) behaviour within a bigger time in the loading phase (from portside to starboard) due an unbalanced load setting. The sketch shows a schematic load distribution at about half of the loading process. At this time only the starboard side is already loaded with cargo in order to avoid additional load obstacles for the loading process on the portside where the ship has its only load possibility.

It is also notably that the first part in ARIZ [9] can be also understood as several “clusters”[10] where “model your (SuF) problem” which is also an indication to use this time period carefully for solution finding also when generating SuF’s. When thinking about the interacting components several constellations can be made. Although the cargo seems to cause the problem at first glance, the identification of the system that needs to be improved can be identified as a “balancing of the ship”. This reduction of the problem focuses on the harmful movement of the ship itself, opening solutions to the user of the algorithm that will not affect the amount of cargo nor the loading strategy that would be an intuitive approach.

Also the second cluster (“resource analysis”) requests the user to think better about the existing components (of the SuF) and alternative combinations. Those “other” components (port, loading ramp, water) seem already to satisfy requests for the “additional components” (e.g. standard solutions 1.1.3/1.1.4/1.1.5/1.1.6/1.1.7) for a (later) standard solution approach [11]

The third cluster (“determination of ideal result”) also demands to think carefully about the expectation from the final result. This was also understood as a check loop if the solution is able to provide a sufficient result. Also a hint can be seen here to focus on a single (physical) contradiction that also forces the user to compare different several models in terms of effectivity to the final result.

Cluster 4, the “utilisation” of resources (“what can be used as switch/tool to solve the situation”) is especially focussing on realisation possibilities, reducing the found amount of SuF’s to “more practical one”. This can be very useful as it allows a kind of classification for the realisation possibilities from the user point of view that might be similar to later approval people.

There are also different algorithms for SuF’s[12] that focus deeply on the step-for-step generation of a SuF and investigations to the relation of SuF’s to the innovative principles [13]. This indicates that the generation process can be made successfully on many ways when spending sufficient time with sub-steps and preferring a specific order that starts with several limitations (also of rules). When talking about mind funnels we should not forget that some bigger funnels can be also used for a collection of ideas. If we lack of (good) ideas we need to use bigger “funnels” as a kind of “idea” collectors, accept also “grey input” and modify the found (off-grid) results in a way that they fit to our requirements in the end. Within this modification process additional solutions can be found that can improve the final result in quality and quantity.

### 3. Conclusions

It is very tempting at the start of a solution finding process to tick off items on this ARIZ list with “fast” answers, especially when only interpreting SuF in TRIZ as a “cooking recipe” method. The method allows not only to scan a problem field by a regular scatter search in order not to forget or oversee a (more simple) solution instead of the usual “try and error” it also has other benefits. One of the major learnings from this algorithm in practical environment can be seen in a better understanding of the problem and the possibility to get several models of the problem. It is recommended not to “hustle through” the items (“just” to get a perfect result) but to think carefully in several loops from different directions about the topics. The time spent with the sub-steps can be seen as the foundation of the later (better) solutions that require a deeper understanding of the situation. This can be perceived as an advantage, as those solutions are very unlikely to be found with unstructured methods. When moving from obvious practical problem descriptions to more analytical approaches like finalized SuF’s, the “mixed zone” between also seems to contain several solutions worth to spend some extra time “between” the starting position and the several analytical final results. Solutions that seem to satisfy several models (at least) partly turned (on a regular basis) out to be sufficient stable and robust. It seems also very likely that those results are more able to survive the approval process with only slight modifications as the realizing timing and already existing experience in this field seem to match better than “off-grid” solutions in practical environment. People seem not only to have a better motivation to use this methodical approach for their solution finding process; while accepting intermediate models of their own, also the resulting amount and quality (also of final models) seem to be higher within a practical environment limitation.

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**Communicating Author:** [michael.schoewel@live.com](mailto:michael.schoewel@live.com)

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**TRENDS OF ENGINEERING SYSTEM EVOLUTION IN TOY /  
KIDS INDUSTRY**

Jerzy Obojski,  
*Novismo, Warsaw, 02-672, Poland*

**Abstract**

This article aims to demonstrate an unconscious use of trends of evolutions in technologies, which up until now have been used in product development process. It is also an attempt to trigger a discussion over TRIZ application in “toy / kids goods” industry for the further development of new stuff which will be practical, useful and convenient in use for very young persons.

The author examined a number of different types of equipment for kids in terms of trends of evolutions and would like to present observations about some patterns related to evolutions of goods designed for adults.

Very often toys or equipment for kids are smallest copy of products dedicated for adults. Small users simply can't properly operate them due to lack of skills or experience. Coordination between eye and hand in that time is still “under construction” also some parts of muscles are not developed enough.

A few big market successful products presented in this article can point out future of line of trend and will be a starting point to look deeper in this topic. This knowledge can be used to perfectly fit the needs of small customer, build the market competitiveness and achieve the commercial success.

Keywords: TRIZ, Trends of Engineering System Evolution, TESE, secondary problems,

**1. Introduction**

Father of TRIZ Genrich Altshuller try to utilize any patterns which are works somewhere into problem solving and idea generation process. We can link psychology, behaviourist and physiologist knowledge with this what TRIZ offer. It was good but sometime doesn't works well. Finally the focus and attention were pointed on biology. Altshuller ask itself what is the secret behind facts that some live organisms are survive and some not. The good explanation were written in general theory of evolution written by Sir Karol Darwin. [1]

In natural way that theory was used to check if in engineering world are exist some trends or pattern. Finally the Trends Engineering System Evolutions (TESE) confirmed that those patterns are exists.

Today we can count the follow trends: (Fig.1)

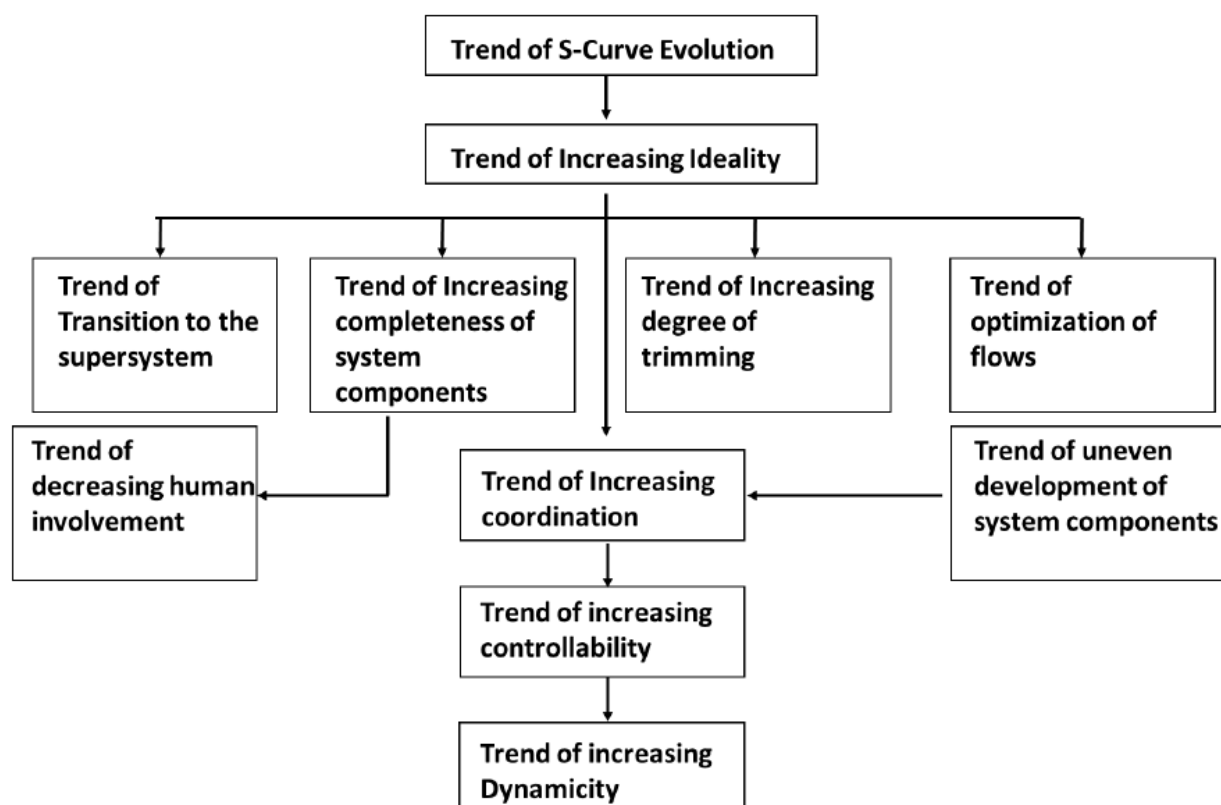


Fig. 1. General structure of TESE

Different sources says about different numbers, but fact that they are exist is now so obvious. With Trends the situation is not much better than with Analytical tools. The Trends that are usually taught are from 1985 that is how Altshuller formulated them on a very generic level. He himself pointed out that those trends are more philosophical than for practice. Since then a lot has been dome, some things published, but 90% of trainers still stupidly repeat the variant of 1985. They just beautify them with some twists- Radar Trends diagrams, etc.

In 1997 Altshuller tore the Radar Diagram approach into pieces. By now there are sub-trends that clearly show that the evolution can go both ways of the trend depending on a number of conditions, so to build Radar diagrams is totally useless without understanding in what direction of the trend the evolution should go.[2]

This trends structure is very general and capacious. Nowadays any new try for adding a new trend usually has this same effect – it is possible to classify a new one as a sub trend of existing one. That is very good information for us because that is mean that basement created by Altshuller is still valid. Let's focus how we can use it in practical way.

## 2. Why we improve technical systems?

A technical system is created to serve a certain purpose which, in turn is realized through the so-called Main Useful Function of the technical system. Appearance of a system which delivers a specific function which has never been delivered before on the basis of selected physical means results from the highest-level invention, which is usually a pioneering or disruptive invention launching a new technology. [3] In turn, the Main Useful Function targets at providing the best fulfillment of major features which represent core values of a technical system. For example, the first phonograph device which used a wax cylinder to record sound invented by Thomas Edison originated the entire technology of sound recording which went over hundreds of years of evolution and included a number of disruptive innovations: vinyl recording, magnetic recording, digital recording. Although any later invention which made sound recording possible but used a radi-

cally different basic operational principle can as well be regarded as pioneering, it is better to use the term “disruptive innovation” rather than “pioneering invention” since it does not start but only continues evolution of the entire technology. We therefore call invention a “Technology Originating System” (TOS). Not too many technical systems can be considered as originating entire new technologies.

From that point of view invention of a bicycle which we will be using throughout the rest of this article can probably not be called really pioneering since the function of personal transportation had already been executed by earlier technical systems – for example, by a cart with two or more wheels driven by other men or a horse. However the first bicycle made it possible to travel without help of external force and therefore it was both radical and disruptive innovation thus it can be called TOS.

Although some ideas of a bicycle can be found in sketches by Leonardo da Vinci and his students, the first working bicycle known as “Hobby Horse” was invented in 1817 by Baron von Drais [4]. The machine included a frame, two wheels, a steering wheel, a saddle, and was made entirely of wood. The first bicycle did not have pedals and was moved by a rider using his feet to push on ground. However it was the first technology originating system which included the lowest number of subsystems to implement the main function of transporting the rider by using the operational principle of utilizing muscular force of his legs.[5]

### 3. Not only forward.

Using a bicycle examples let’s analyze the case study about Balance Bike.



Fig. 2. The first Balance Bike for kids. (1990)

The first time two-year-old Niklas Mertens climbed on his father’s handmade plywood version of a children’s bicycle and took a ride he attracted a good deal of attention.

“People just gaped,” says Rolf Mertens, then a designer for a computer magazine, remembering the sight of the toddler wheeling about in a pedestrian zone in Aachen, Germany. “They had never seen a two-year-old zip around like that.” Niklas’s mother, Beate, says: “He got on and took off. He only stopped for meals and sleep.”

The husband-and-wife entrepreneurs knew they had found a winning idea that spring day in 1990. By summer they had named their fledgling company Kokua and by October they were making the Like a Bike – a pedal-less wooden two-wheeler that sparked a revolution in the market for children’s bicycles. (Fig. 2)

Their manifesto was straightforward. Instead of putting toddlers on chain-driven bikes with stabilizers, parents should introduce them to the tricky art of balancing using a bicycle that asks riders to push along with their feet and free-wheel when they can.

German inventor Karl Drais had first thought up an adult version, known as the “draisine” or “dandy-horse”, in 1817. (Fig. 3)



Fig. 3. Karl Drais and his “drasine”.

Its rebirth as a children’s craze began in the 1990s, when the German Bicycle Club began advising members such as Mr and Mrs Mertens to take the pedals and crank off a kid’s bicycle rather than fit stabilizers in order to teach children how to balance.

Instead of messing about with mucky, stubborn bicycle parts, Mr Mertens reckoned he could just do what Drais had done – build a bike himself. An industrial designer, he was also a member of a local woodworking club.

“Woodworking had always been more than a hobby,” he says. “I had always been looking to make something we could market properly.” After past experiments with everyday objects such as salt and pepper pots, he had come up with something novel.

Mr Mertens is proud of his ingenuity, but says he made one mistake. “I was in a hurry and I didn’t think of filing a patent on certain technical solutions.

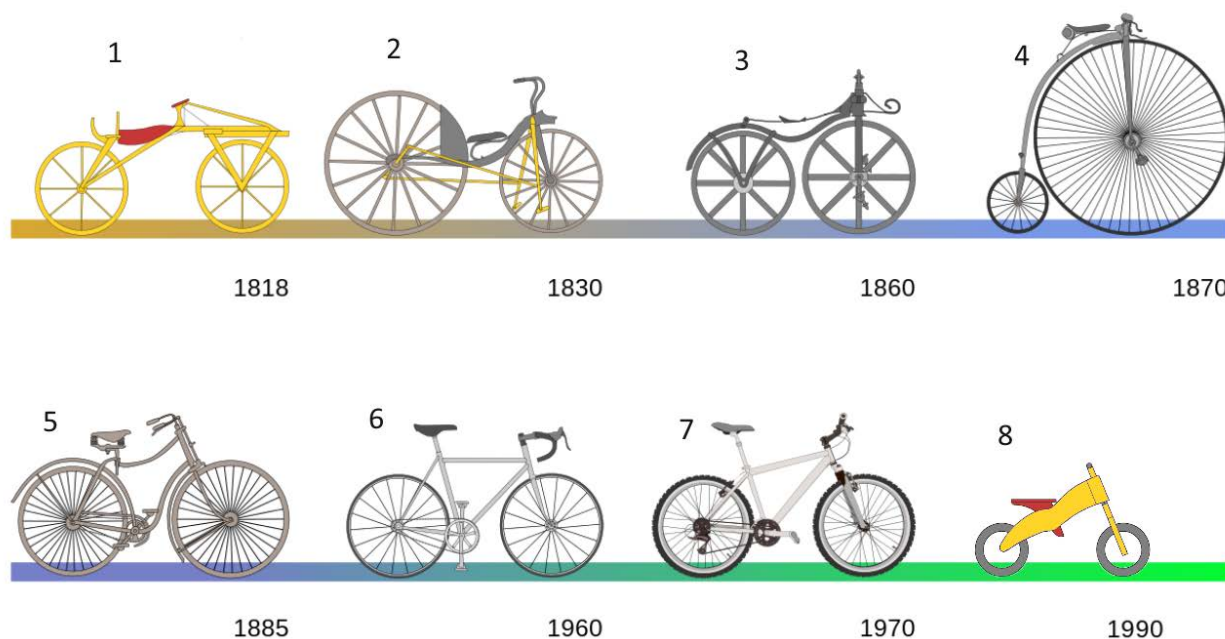


Fig. 4. Evolution of Bicycle, picture excerpted from Wikipedia.

## 4. Discussion

We see that in today's fast moving and competitive world, development of products, technologies and services are looking forward. A generic product or technology usually are no attractive. At present, the Trends of Engineering System Evolution has been described by using trends and sub-trends. However as usually the people thinking that evolution should goes only in forward. The TESE helps to derive hypothesis in a promising system development direction. Engineering system evolution principles usually are not easy to use it in practice. Development of goods can direct in many directions, as many have a trends and sub-trends. It is not quite applicable if we want to exactly predict the future, because when we use these principles, we could easily list different future alternatives, but it's not straightforward for exact predicting the future of products. If we apply engineering evolution principles to a bicycle, it's easy to list the future options, for example, following the trend of increasing completeness of system components, there is the version of electrical bicycle; following the trend of increasing controllability, there is the version of better control of saddle. However, there are different component within a bicycle, which one will evolve faster than others are? On the other hand, will they evolve at the same speed? If we pick one subsystem, for example, the saddle of a bicycle, which trend will it follow? TESE did not answer these questions. The ultimate question for engineers is what will be the most successful/dominating product in the market in the coming years, but TESE does not answer this question.



## S-Curve

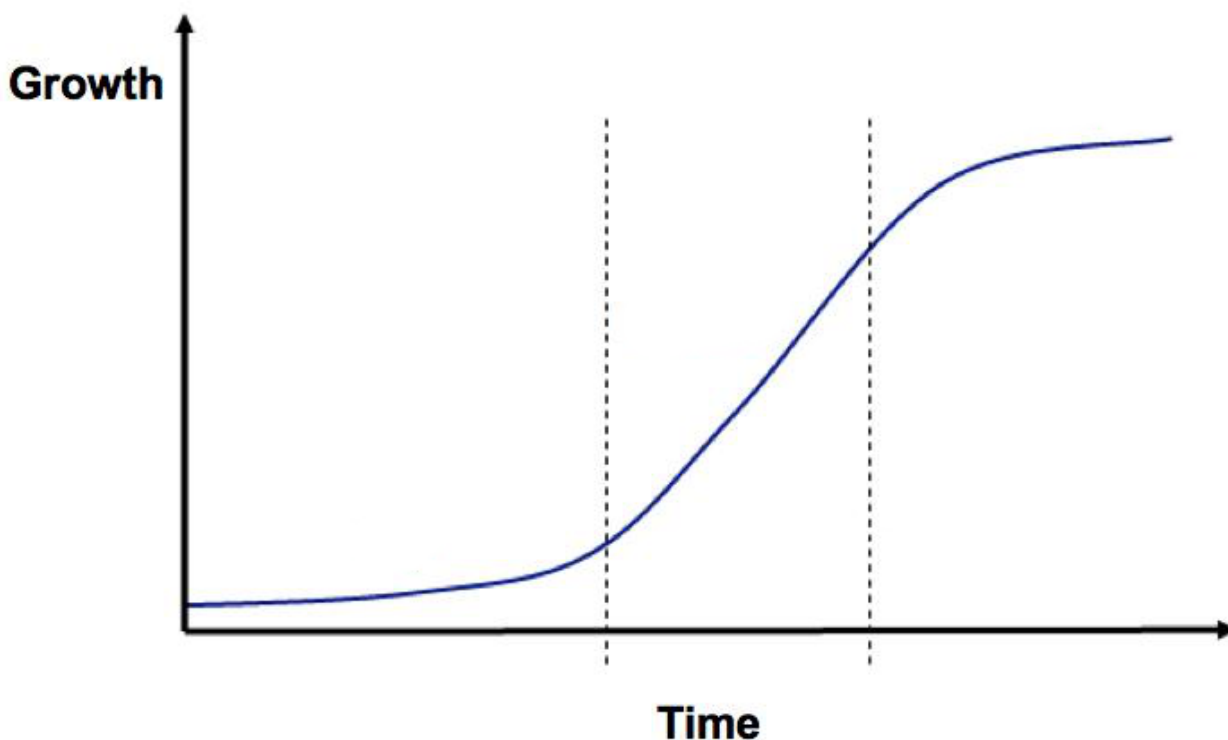


Fig. 5. S-curve – One of the most often used trends for prediction the next stages of evolutions.

The second challenge comes from the scope of a system. When we talk about S-Curve of bicycle, we could refer to S-Curve of bicycle as a category, we could also refer to a certain type of bicycle, e.g. mountain bike; even we could refer to a more specific brand, e.g. Giant. When we talk about the S-Curve of the generic bicycle, then it refers to the whole history of bicycle shown as below. (Fig. 4)

But the history and future of a bicycle does not make much sense for a product designer from a specific company such as Giant, because the designer's objective is to launch a new product within one year, rather than 30 years in the future.

Shpakovsky [6] suggests that we should use Evolutionary Tree to predict the future. Which is more applicable in practice because from two reasons. Firstly, the Evolutionary Tree pick a single function as a subject of evolution. For example, a bicycle has different functions, but if we want to predict the future of bicycle, we have to pick one function of bicycle, e. g. moving people. Then we could start to predict the different products that will be serving the purpose of moving people. Secondly, The Evolutionary Tree combine all principles together, so that people could apply the principles consistently.

In this article, we would like to build on the previous literature and further improve the way we predict the future.

This case study immediately bring a question: Why this old idea (balance bike) was so successful?

In the author's opinion there are several factors affecting this:

- Surprising effect (everyone heard and seen drawings the first version of bikes)
- First users like kids don't have a needed skills before
- Solution was so simple
- Good enough
- Enjoy a small users

Next question:

Do we can find other examples to see that very primitive solutions can be easy apply to using by kids?

As a results of this consideration there are three examples below.

#### *Example 1*

**Cut with classic scissors** – Trouble that we see when children try to cut a paper by using a scissors are related to the proper operate two fingers. It is very difficult for kids open and close fingers, in this same observe a line of cutting and hold fingers in the holes. It is not obvious for them that when they move fingers in this same time in the opposite end the blades are cut paper or open. It is a long and painful process to learn this skills. Additionally, the force that they apply for a circle grip create a very bad perception, and only they own determination or request from a parents make that this is process continued.

When we back to the beginning of evolution of scissors we can recognize that the mechanism was different, than we have now. Blades were connected with spring holder and the cutting process was made by whole hand. The skills of grabbing something by whole hand are more natural and the learning process is easier.



Fig. 6. Ancient Greek scissors.



This same principle we can find in scissors dedicated for very small kids (Fig.5). The plastic grip can hold whole hand (like in the ancient scissors) and way of operation is exactly this same. Spring-action design opens blades after each cut to help kids learn a proper cutting motion. Blunt safe blades cut paper only to protect children. As producer suggest this kind of product can be used by kids after third years.



Fig. 7. Modern scissors for kids.

### Example 2

**Throw object for a long distance** - Trouble that we see when children try to throw an object for a long distance are related to the proper coordination whole body, with hand and fingers. Any delay, wrong timing has a big impact for achieved distance. Not impressive achieved distance make a kids angry, and they slow down the learning process. At the moment when the achievement is improved they intensify numbers of tries as a results at this same time make big impact for coordination's of body. Can we make this activity more attractive and avoid some period when the achieved results make more disappointments than satisfaction?

When we back into history and analyze how the first human resolve this problem, we can find a several simple methods how to do that. One of them is Atlatl – very primitive weapon used from 30000 years ago.



Fig. 8. Atlatl – ancient tool that uses leverage to achieve greater velocity in dart-throwing.

The extension length of arm has a big impact for achieved distances. In that case perfect coordination of body don't have a minor role.

This same a principle we can find in nowadays toy. (Fig. 5) Plastic spring lever, have possibility to temporary hold a ball. Grip make more comfortable operation, extension give possible throw the ball far away. Long distance shoot now is a no problem even for a kid. Achieved results are over expectation according the previous experience, so kids try again and again. During the time a new skills are more repeatable so achieved results are stabilized.

Below is shown toy for plying with a dog. Now it isn't a painful experience shutting a ball many times even for a small user.



Fig. 9. Toy for playing with dog.

### *Example 3*

**Painting with paints and a brush** – Trouble that we observe when children try to painting by using a brush are related to the proper holding, coordination arm and hand and react for that what they are seen as result. Any wrong movement or delay has impact on quality of picture. Some kids starting to be angry, and as a results instead an intended movement of brush, they move everywhere. As a results the final output completely not satisfy the creator and for some period of time this activity is not repeating.

When we back into history and analyze how the first human make a pictures, we can find the simplest solution. They do it by his hands. First it was just copy of hands – some amount of pigment on the skin and a little of force make a very good results. The quality of details and achieved effect make the creators happy. After than they want more, and they start experiments with fingers and any other, simple shapes. Again, during the time the skills are trained more, and the achieved results are more satisfy.



Fig. 10. Cosquer Cave, France c25,000

By using analogy – the solution is obvious. Instead teach kids how to use a brush, let's start from hands and paint. This way of introduction a small creators in to art can by very fun, and generate a development a coordinating and manual skills.



Fig. 11. Kid, paints, paper and hand.

## 5. Conclusions

Presented examples showing an interesting niche for a specific goods where the customer don't have a big experience and skills in using any tools or from some reason that skills are reduced. In that case to satisfy the expectations it is needed to move back in the Trends of Engineering System Evolution. Instead adding functions, features, drive, controllability etc. its needed start from beginning and adjust product or process for a final users. Consequently, to uncover potential

for new goods the TESE provide excellent opportunities. Working through the mechanisms and tools for each trend will bring up a lot of possible directions how to simplify a products, processes and services in terms of specific segment of market – toy / kids industry.

The easiest way to meet with the technical artefacts is go to the museum. Repeating case study of Balance Bike made by Mr Mertens, the inspiration were taken from observation of exposition. The rest of the stories are chain of events and needs to verification on real use.

Using the technical information and the first hand impressions observing the artefacts, the structural knowledge about the trends can be also consolidated. Furthermore the critical examination of artefacts leaving or interrupting trends supports the reflection of the meaning and use cases of the TESE. So a much more differenced evaluation of the learning content can be done by the participants, what especially was fostered by the need, to present their results to the other. At the end this need for explication is the most important step of the examination, is that observation make a sense.

What else we can do after the finding a good artefacts:

- use function analysis to create a function model of two different artefacts of the same technology and try to explain the technological evolution step using the models created
- more closed learning settings may contain more detailed task descriptions, forms to fill in, checklists for gathering artefacts as examples etc.
- more self-organized learning settings may support the consolidation of knowledge by even more fuzzy tasks and expectations regarding the results;
- examine the evolution of a chosen technology and try to identify different stages or changes and document your insights to use it later in the class
- identify the appearance of each inventive principle in just any artefact
- identify the appearance of as much inventive principles as possible in the range of one chosen technology
- similar tasks with inventive standards
- use the cause-effect-chain-analysis to explain, why a specific technology changed dramatically

The authors would like to emphasize the huge potential of opposite flow analysis of trends with an exhaustive set of recommendations on how to improve development process of new products for toy / kids industry. If applied to this opposite flow analysis of trends can be a powerful method for improving processes and products with respect to final user expectations. Trends of Engineering System Evolution are especially helpful for creating innovative and user friendly goods. The method can be applied to visualize the current state concerning the technical evolution state and recognize the simplest way to deliver desired function. The current state can be used to derive improvement hypothesis which can be tested as experiments in short product development cycles. Inventive ideas can be verified whether they are compliant to the expected next step concerning development of the product or service.

Author wants to start discussion over TRIZ community: How this observations can be utilized, commercialized for specific type of goods development like toy / kids industry. The authors consider the next steps to be the development of more practical recommendations on applying TRIZ tools in connection with the concept of opposite flow. In addition, some real case studies must also be developed.

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**Communicating Author:** [jerzy.obojski@pl.abb.com](mailto:jerzy.obojski@pl.abb.com)

## **TRIZfest 2018**

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# **RESEARCH ON CULTIVATION MODE OF CONSULTANTS IN TRIZ METHODOLOGY**

**Alp Lin**

*Beijing, China*

### **Abstract**

With the popularization of innovation methodology TRIZ in China, people pay more attention to the practice and application of innovation methods. How the innovation of methodology in combination with the practical problems, how to develop a group of creative ability for the enterprise consulting experts, how to combine innovation methodology with technological breakthrough, product research and development, production practice and scientific research projects.

It is urgent to improve the efficiency of enterprise research and development and achieve breakthroughs in core technology, new product development, and process improvement and production operation.

People who know the innovation methodology TRIZ are weak in professional ability and engineering experience, and engineers with profound engineering background are weak in understanding and application of the innovation methodology TRIZ. How to combine the two with opportunities to cultivate talents with the application of composite innovation methodology has been put on the agenda, which is an urgent and arduous task.

If you look at the top 10 consulting companies in the world, they have the common characteristics: method, team, service and brand. There is a senior team of experts, with their own mature methodology, their own expertise in the field of services, do something or do nothing, to build their own brand advantages.



Company	LOGO	Technology Strategy	Team	Service(Trades)
McKinsey & Company		Three-level theory and 7S model	9000 consultants	For presidents, senior executives
Bain Company		"Main profit" seeks continued earnings growth	5000 consultants	Strategic decision, e-commerce
Boston		Boston matrix leads the pack of consulting tools	4400 consultants	Strategy consulting, privatization
Monitor		Harvard University background, porter five forces model	700 consultants	Strategic consulting, academic background
Arthur D Little		Focus on technical issues, scientific areas	1800 consultants	Patent consulting, information technology
Booz Allen Hamilton		Solve the "CEO level" problem	22000 consultants	Integration strategy, Government agencies
Mercer Consulting		National economic research association, listed insurance	18000 consultants	Financial services, transportation
A.T. Kearney		Excellent collaboration, become a partner	2000 consultants	Focus on the enterprise
Accenture		"Intellectual capital" is <u>accenture's</u> most valuable asset	150000 employees	Management and information technology
RolandBerger		Innovation strategy to win, and grow together with customers	1200 consultants	Strategic consulting, academic networking

## 1-Requirements on the ability and quality of innovative consulting experts

*Innovation consulting experts*: refer to the instructors who guide, train and train engineers in the application of innovation methodology. Combined with my own professional technology and engineering experience, I applied innovation methodology to instruct others to analyze, solve and provide solutions to consulting experts, and taught innovative methods to improve the organizational intelligence of enterprises.

### 1.1 basic qualities of innovative consultants

- *Theoretical Knowledge*
- *Engineering Practical Experience*
- *Master counseling techniques and go through special training in consulting.*

Consultation is a kind of mental work with high intelligence and high intensity, which determines that the consultant must have high quality, theoretical knowledge and experience in consultation.

### 1.2 Responsibilities of an innovation consultant

- provides methodology guidance to industry engineers to solve problems
- The instructor of the engineers to analyze and solve the problem
- In the project, the conception of large frame, indicate the direction of technology
- Implementation methodology innovation and engineering technical problems
- Guide engineer to use application innovation software to solve practical problems;
- Preparatory to provide direction for the enterprise, the perspective technology password cracking rivals
- For policymakers act as advisers, the role of staff and regular
- Help companies and engineers to solve technical problems, identify, and to grasp the method of innovation, through intensive study and implement, improve to achieve the business goal of an independent, professional intelligence service.

### 1.3 Five abilities of innovation consulting experts

#### ◆ *Problem Insight*

1. On-site research ability
2. Ability to recognize needs
3. Problem definition capability
4. Project decision-making ability

#### ◆ *Systematic understanding*

1. ability to think systematically
2. System analysis ability
3. System coordination ability
4. System development capability

#### ◆ *Professional problem solving ability*

1. Professional engineering skills
2. The ability of method application
3. Ability to learn independently
4. Problem control

#### ◆ *Technique Foresight*

1. Product planning capabilities
2. Technical forecasting ability
3. The ability of competitive perspective
4. Ecological awareness

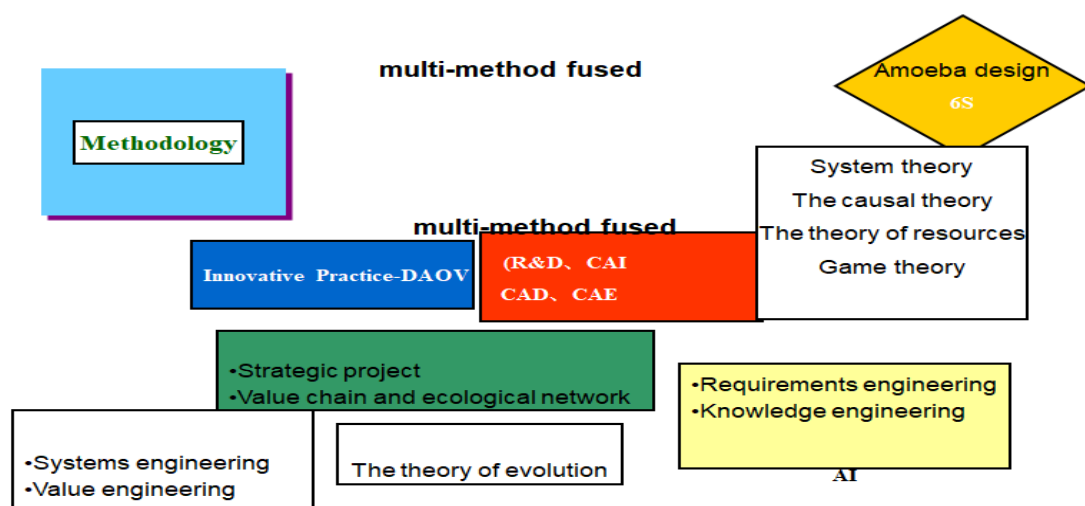
#### ◆ *Advisory guidance ability*

1. communication skills
2. ability to lead research
3. ability to work together under pressure
4. Project control

## **2-Innovation consulting expert training tools and programs**

2.1 The cultivation of innovation consultants depends on the combination of innovation methodology TRIZ and multiple methods. The application of multiple methods, combined with the actual situation of the enterprise, builds the implementation process of innovation methodology, establishes the application system of innovation methodology, and builds the application platform of innovation methodology.





## 2.2 Training objectives of innovation consulting experts

Overall objectives: around the five kinds of ability of consulting experts, i.e., problems found, system control, subject combining ability, technology foresight and the improvement of method guidance ability to carry out targeted design, training, drills, actual combat, check, etc., combining with practice, theory and subject combination, combination of training and project to complete the cultivation of the innovation consulting experts.

Design as five modules:

1. *Problem found*- Objective: to identify real problems, not imaginary, but real, objective, and actual
2. *Problem analysis*- Objective: to analyze problems from a multi-dimensional perspective, to analyze the system from the perspective of system function, to view problems from the perspective of reason correlation, and to explore ways from the perspective of resources
3. *Problem solving*- Objective: to explore the principles, methods and tools of problem solving, and to explore solutions based on knowledge, experience and model
4. *Plan implementation*- Objective: to examine the knowledge connotation behind the solution, to recognize the progressiveness of the solution, the enforceability based on constraints, and to realize the value of the solution
5. *Technical Prediction*- Objective: to understand the technological evolution trend based on scheme, the overall development direction based on system, and to understand the technical atlas of competitors

## 2.3- The cultivation program of "five forces" of innovation consultation experts

1. *Problem insight training tool*:
  - Design of enterprise innovation questionnaire
  - Assessment of enterprise innovation capability

- The process of field research, the design of content and the writing of reports
- Demand analysis
- VOC, VOB, and MPV analysis
- KJ, Parleito, QFD, SIPOC analysis
- Analysis of enterprise pain points
- Project profit and loss point analysis
- Decision analysis
- Writing project approval report
  
- 2. *Training tool for system thinking ability:*
  - System analysis
  - System analysis and reduction
  - System dynamics
  - System flow and domain analysis
  - Value analysis of system components
  - System component ideality diagnosis
  - System tailoring and inheritance
  - Systems genetics
  - Resource analysis
  - Resource pooling
  - Causal analysis
  - System key factor analysis
  - FMEA
  
- 3. *Problem-solving tools:*
  - innovative problem solving principles
  - innovative problem solving
  - innovative problem solving knowledge base
  - innovative problem solving effects
  - innovative problem solving processes
  - innovative problem solving models
  - invented the problem solving algorithm ---ARIZ
  - ten industry classic case sharing
  - 10600 selected project case sharing
  
- 4. *Tools for product forecasting:*
  - product life cycle theory
  - S curve theory
  - the evolutionary laws of technical systems
  - the evolutionary tree
  - product technology prediction technology
  - product technology planning, value network system, and ecological network analysis
  - core technology perspective, product competition trend analysis

- product technical route map
- product evolution strategy map
- intellectual property strategy, patent layout and evasion

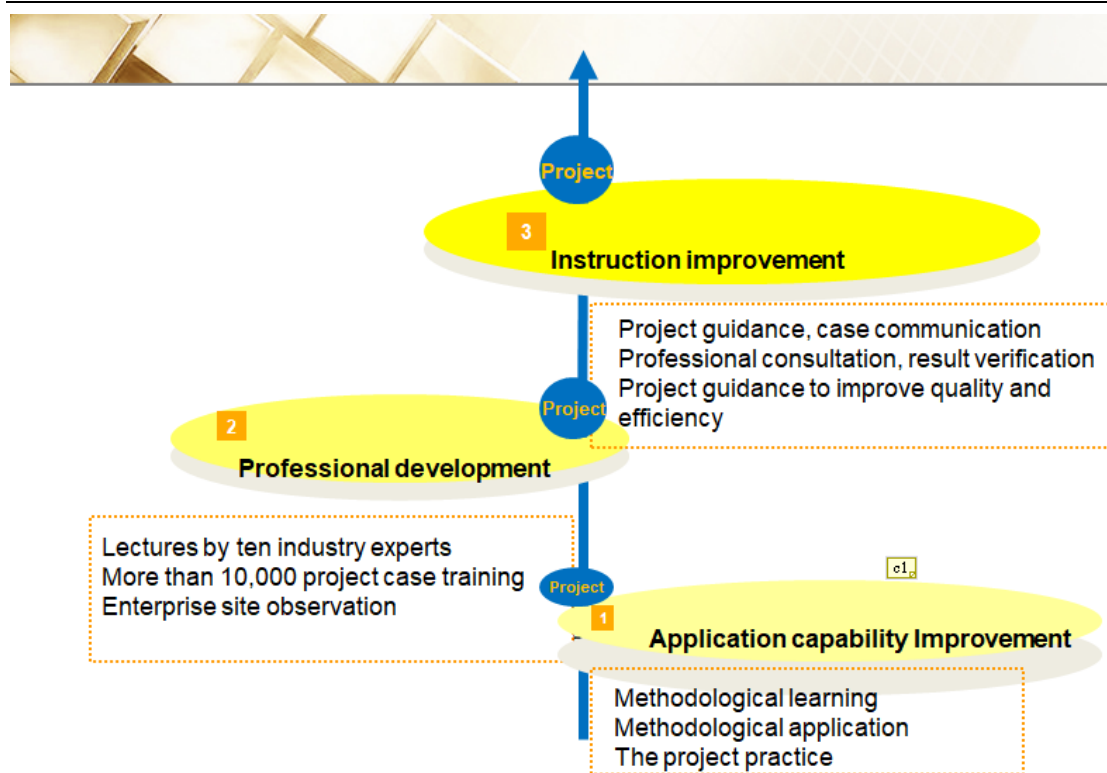
5. *Consulting guidance, training tools to verify implementation ability:*

- program evaluation and validation
- DOE analysis
- CAE, additive design
- communication and communication skills
- presentation and presentation skills
- project management
- 4D leadership
- innovation executive
- the writing of concluding and guiding reports

**3. Implementation of innovation consulting expert training project**

The cultivation of innovation consulting experts is divided into three stages, with the project as the main line, and the consultation and guidance process is the project as the main axis, and the whole process is coordinated.

- A. Improvement of methodology application ability
- B. Improvement of professional competence -- -coordinate the training of ten industry experts, scholars, academicians, craftsmen, over 10,000 professional cases and on-site examination of enterprises (perceptual knowledge)
- C. Improvement of guiding ability --- guidance of enterprise projects, exchange of cases, participation in consulting projects and practical guidance. I guide you to observe, you guide me to observe, you guide me to evaluate, correct mistakes, feedback etc.



## 4 Conclusions

The cultivation of innovation consulting experts plays an important role in the promotion of TRIZ, and TRIZ can be introduced into the enterprise more effectively. We have explored and practiced the proposed model, and we will continue to introduce the model, methods and tools into the enterprise and constantly improve our model.

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**Communicating Author:** Alp.Lin@iwintall.com

## **TRIZfest 2018**

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### **THE TRIZ INTRODUCTION AT THE ENTERPRISES OF THE GROUP OF COMPANIES BASIC ELEMENT**

Sergey A. Yakovenko<sup>a,b</sup>, Alexander V. Kudryavtsev<sup>b</sup>, Viktor E. Minaker<sup>b</sup>,  
Elena V. Redkolis<sup>b</sup>, Andrey A. Tarasov<sup>b</sup>, Naum B. Feygenson<sup>b</sup>, Mikhail S. Rubin<sup>b</sup>,  
Nikolay E. Saunin<sup>b</sup>, Yuriy N. Litvak<sup>b</sup>, Andrey B. Rozhnov<sup>b</sup>, Boris I. Tkachev<sup>b</sup>,  
Alexey Y. Fomenko<sup>b</sup>, Oleg M. Gerasimov, Yuriy V. Lebedev<sup>b</sup>, Sergey A. Logvinov<sup>b</sup>,  
Sergey A. Kondrat<sup>b</sup>, Nikolay A. Schedrin<sup>b</sup>, Vladimir N. Nikitin<sup>b</sup>,  
Evgeniy V. Panchikhin<sup>b</sup>, Mikhail A. Scherbakov<sup>b</sup>, Oleg A. Kraev<sup>b</sup>

<sup>a</sup>*Moscow State University, Faculty of Physics, Moscow, 119194, Russia*

<sup>b</sup>*TRIZ Departments of RUSAL, BasEL, En+, Moscow, 141096, Russia*

#### **Abstract**

The real experience of a wide integrated TRIZ implementation at the enterprises of a large international concern, Basic Element, is shown. The components of the complex implementation work are disclosed, which ensure the efficiency of implementation and quick access to real practice. Typical difficulties encountered in such implementation and general directions for their elimination are shown.

Key words: innovations, TRIZ, TRIZ implementation, TRIZ solution implementation

#### **The history of the issue is the introduction of TRIZ at Russian enterprises**

The Russian Federation as the legal successor to the USSR can show the longest possible use of TRIZ tools. The recent ten to fifteen years gave several interesting examples of the TRIZ introduction in large and small enterprises. Currently, the metallurgical giant EVRAZ is applying TRIZ for the training of young engineers and for solving internal shop tasks at its enterprises. TRIZ methodology is applied at the metallurgical enterprises such as Severstal, NLMK Group, OMK, Rusnickel, titanium producer AVISMA, a number of Rosatom enterprises, Rostec corporations and others. At the same time, in most cases these are examples of partial implementation – the use of TRIZ to perform certain functions, for example, to increase the creativity of young professionals, to solve specific tasks, etc.

#### **The history of the TRIZ introduction at Basic Element**

Methodological tools that involve the identification and subsequent solution of problems are applied at the enterprises of Basic Element for a very long time. First, these were tools that ensure the establishment of order, saving resources, eliminating unproductive losses. The Toyota Production System (TPS) method was the basis of this process. After adapting to local conditions and wide implementation of these tools, the decision was made to introduce TRIZ, the Theory of Inventive Problem Solving, into the manufacturing process [1].

The experience of firms using TRIZ was studied and, in the end, the version that showed the greatest efficiency and the most popular version of TRIZ GEN3-ID was chosen as the basis for the start of implementation. This version is adjusted considering the actual experience of recent years and the specifics of enterprises comprising the corporation.

## **The main directions of TRIZ introduction in the enterprise**

The problem of the organic introduction of the tool into the fabric of business can be decomposed into a number of components. Among them are the solution of organizational issues, and the issues of merging the new structure with those already existing, as well as personnel problems.

## **The basic problems of the enterprises implementing TRIZ in Russia**

The TRIZ introduction, as well as the introduction of any comprehensive system in the organization and management outline is quite complicated, multifaceted in the long-term. At the same time, it's important for the key employees of the enterprise to be included into this process, to understand its goals, stages of implementation, and to be ready for long-term and comprehensive efforts to root and develop a new tool.

Today, the dominant attitude in many enterprises results are rapid and leads to the fact that employees acquire the technique of doing business, but often don't get the most important thing – new thinking, a new look on the working process.

In general, the key problem of implementation can be called a lack of understanding by the top management of the company of both the complexity of the tool and the complexity of the process of its implementation. Fortunately, in Basic Element top management represented by the main shareholder is well aware of this situation and is ready to build the implementation process in the most effective fashion.

## **Finding a strategy for the implementation and use of TRIZ**

Forming a strategy for using the tool is the most important part of work. Without this step the tool is likely to remain one of the most interesting and exotic innovations, which have not found applications. But the formation of strategy is impossible without a deep understanding of TRIZ, its capabilities, types of tasks and the necessary resources. Traps of superficial and overly optimistic vision of the method are possible. Within such approach it's a priority and accepted that TRIZ allows to solve easily and quickly a problem of any orientation and any complexity. This approach is closely related to the view that knowledge of TRIZ allows to solve complex problems even without knowledge of a specific subject area. The clash with reality will not be ending well for the apologists of this approach.

The opposite view is also wrong – to view TRIZ as something completed in the 1980s, as the means of identifying and resolving contradictions. This narrow approach is also not constructive, as it does not reveal important and powerful modules developed over the past thirty years.

Various modules of TRIZ provide an opportunity to apply the method both within the framework of narrowly understood innovation activities, that is, in the shops, in the application to the already used technological processes, and for the development of new products, as well as for the formation of business development strategies and forecasting future threats and opportunities.

In Basic Element, the members of the various strategic committees, involved in the development strategies of individual enterprises, were introduced to TRIZ.

The Basic Element shareholders set the task of training 72000 engineers and managers, working at various group's enterprises, in TRIZ by the end of 2020. It was also stressed the necessity to simultaneously develop some 500 people into professional problem solvers, using TRIZ tools. In turn, all this work required preliminary training of hundreds of internal coaches in the TRIZ.

A current key point of TRIZ implementation work is the connection of TRIZ tools and procedures used by the Corporation for planning and developing new products (PPDS). The complementarity of the capabilities of these tools allows to reinforce the progress of work on the creation and implementation of new solutions.

### **The organizational structure of the Management of TRIZ**

The Management of TRIZ introduced into the staff list of the Corporation: currently includes three Departments:

- TRIZ training,
- Implementation of strategic projects,
- Development of TRIZ tools.

The Management has the capacity to increase the number of employees both in the Headquarters and in the enterprises. Regional branches have been established in a number of cities, and this work is continuing.

The special feature of Basic Element is a wide range of business areas – from power generation at hydro – and thermal power plants, production of aluminum and a number of other metals, alloys, to a wide range of engineering products, as well as service enterprises, enterprises of the agricultural sector, construction industry. All this makes it more difficult to organize a unified system of training and problem solving.

### **The search for qualified employees**

It has always been a difficult process to find employees who could take on the organizational efforts at the initial stage of implementation of the enterprise, as well as providing qualified training and quality support in the process of solving problems. Russia currently has a significant number of highly qualified specialists with both problem-solving experience and teaching experience. This did not solve the problem of personnel for the Management completely, but somewhat smoothed out the severity of the problem. Currently, the Management of TRIZ enterprises employs about forty full-time employees. All of them have real life experience with both foreign and domestic enterprises. Almost all of them are certified by MATRIZ. Seven employees have the qualification of TRIZ Master. In the near future, the number of employees of the Management of TRIZ will grow significantly.

### **The employees training for the Corporation's enterprises**

Currently, the training of employees for the enterprises of Basic element is going in the following directions:

- 1) Review materials on TRIZ, made in the form of the comics shown by internal television Corporation.
- 2) Articles in the corporate magazine.
- 3) Video course of 40 minutes – for very busy managers.
- 4) Workshops for professionals who need to solve their production tasks. The workshop program has a duration of 72 hours (three workshop sessions, each for three days, with breaks between them of one month – "3x3 workshop"). This form of training allows teams that come to solve their problems to get enough time for searching of the necessary information and to have a deeper understanding of the material. In 2018, in the framework of this form of training, more than 400 engineers and managers completed training and work on their tasks.



5) The workshops for internal trainers. For such workshops the specialists, who graduated from the above described 3x3 workshops and who passed the screening committee, are accepted.

The functions of internal trainers working at an enterprise are very multifaceted. These are the participation in the selection of tasks or problem areas offered to employees for the solution, holding of 3x3 workshops, supporting teams solving their tasks, the monitoring of solutions implementation and participating in solving of secondary tasks.

The duration of training of such specialists is very long: there was adopted a program that has training with 400 hours of lectures (four two-week workshops) with a break of one month and a half.

Currently, the training of several groups of internal trainers, with a total of 38 persons, takes place.

6) For specialists who will be engaged in the professional problem-solving of the enterprises' tasks, it's also planned to conduct internships as part of work teams composed of TRIZ professionals carrying out their projects.

7) A separate point is the search for new employees outside of enterprises, their selection and training. Thus, an inflow of fresh professional having additional competencies and skills is provided.

### **Establishing contacts with key units of Basic Element**

Linking with the already operating function blocks is an important element of the work. In particular, it's important to establish relationships both with enterprises and with units that carry out related and close functions.

The units responsible for the development of used products and technologies, units that develop new products, units responsible for smoothing out existing production, units that are developing potential partners.

And, of course, the important task is to timely inform the management of all levels about the possibilities and limitations of the instruments being introduced.

### **Preparation of remarkable examples for narrow specializations**

An important task is to demonstrate the effectiveness of the TRIZ tools that are new to the company. The initial stage, at which TRIZ specialists demonstrate cases with analysis of training problems, should take a relatively short period of time.

In order to switch to "own" tasks and examples, it's necessary from the very beginning to organize together with them the training of groups and the solution of tasks in the main areas of business. Of course, it's not enough just to come up with an original solution; it should be made by specialists. Therefore, it's necessary to build a sequence of stages of the found solutions together with the specialists who solved the problems, to promote solutions to implementation and to control at what stage they are.

For example, it's possible to use these stages:

- a solution is found by the team,
- a decision is prepared for submission to the Technical Committee,
- a decision is approved by the Technical Committee and recommended for implementation,
- a project is opened,

- the project is executed and defended.

Of course, the proposed sequence is of an approximate nature, it's determined primarily by internal regulations and standards of the concern.

### Selecting tasks to solve

At the initial stage of TRIZ implementation the main problem with the choice of tasks is that the listeners usually choose the first batch of tasks without knowing the potential of the method. As a result, it's possible to obtain tasks that are not related to zones in which TRIZ feels itself confident, for example, purely scientific tasks, or vice versa, very simple tasks, which do not require use of complex analytical and decision tools.

There is also a possibility that a part of the trainees to be sure in the positive result will bring a task, the solution of which they have already found. It's okay, but it reduces the effectiveness of the work, since the trainees may not see the benefits for themselves, even if the methods will lead to a solution already known to the listeners. Therefore, it's advisable to require teams that solve their problems to offer not one but a series of solutions.

In the future, trained professionals are well aware of what class of problems they can solve, and the severity of the problem is going down.

Managers can provide a significant assistance in the primary selection of tasks, their training program should include special sections on the types of tasks, the selection of tasks, their primary separation from the problematic situations.

### Conclusions

The TRIZ introduction at a large enterprise is a higher complexity campaign. Successful implementation of this work requires an integrated approach and a long-term interest of the top management of the enterprise. It's absolutely necessary to have a working body performing the work – the department, or another unit responsible for the implementation and use of the tool.

This entire task complex cannot be implemented without a presence at the company of large goals for further development that arises the need for an accelerated solution of a significant number of complex technical and managerial tasks.

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Communicating Author: [7909018@mail.ru](mailto:7909018@mail.ru).

# Proceedings of the 14th MATRIZ TRIZfest-2018 International Conference

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Organized by the International TRIZ Association – MATRIZ

Editor: Oliver Mayer

The collection of papers «**Proceedings of TRIZfest 2018 International Conference**» is intended for TRIZ specialists and users: academics, engineers, inventors, innovation professionals, consultants, trainers, teachers.

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

All presented papers are double-blind peer-reviewed.

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