Sebastian Koziołek · Leonid Chechurin
Mikael Collan *Editors*

Advances and Impacts of the Theory of Inventive Problem Solving

The TRIZ Methodology, Tools and Case Studies

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Preface

This book is a summary of conference papers presented at two TRIZ-related conferences: TRIZ FUTURE Conference 2016 in Wrocław, Poland, and TRIZ FUTURE Conference 2017 in Lappeenranta, Finland.

All TFC conferences aim at linking industrial companies, research centers, educational organizations, and individuals to share their experience on systematic inventive processes and to promote TRIZ diffusion worldwide. They provide an international forum for exchanging new ideas on TRIZ and knowledge-based innovation, presenting recent achievements by the TRIZ community and enabling further advances and collaboration between industry and academia.

TFC conferences are organized by European TRIZ Association (ETRIA). ETRIA is an association based in Germany, founded in 2000. It considers itself an open community to unite the efforts, suggest opportunities for global standardization, conduct further research and development, and provide mechanisms for the exchange of information and knowledge on TRIZ and TRIZ-based innovation technologies.

ETRIA has the following goals:

- Research and development of innovation knowledge by integrating conceptual approaches to classification developed by artificial intelligence (AI) and knowledge management communities
- International observation, analysis, evaluation, and reporting of progress in these directions
- Promotion and exchange of information and experience between scientists and practitioners in TRIZ, universities, and other educational organizations
- Development of TRIZ through contributions from dedicated experts and specialists in various areas of expertise

This volume presents a collection of the best papers presented during TFC 2016 and TFC 2017 by the authors from over 20 countries. These authors are representatives of industrial companies, universities, research centers, and consulting companies.

Wrocław, Poland — Sebastian Koziołek
Lappeenranta, Finland — Leonid Chechurin
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Summer 2018

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Digital Learning Design: From Ideation via TRIZ to Implementation

Iuliia Shnai

1 Introduction

The worldwide digital shift influences the majority of the spheres, including education. Information consumption and delivery are realized in fast, flexible, constant, innovative forms. Lifelong learning is not anymore an option, it is a rooted style of doing things. Cultural shift has happened, moving our minds toward self- and guided- learning. Employees expect their future workers to be prepared, even if the person does not obtain the required knowledge and skills in the education institution. In their turn, job seekers are ready to study by themselves to satisfy the expectations of the company. Within the described environment, the place of the third stakeholder, mainly university and other education institutions which teach students in a traditional manner, become unsteady and questionable.

To meet the needs of "YouTube age" learners, ways of knowledge and experience delivery in education undergoes alterations. Traditional learning approaches transit to blended or e-learning, forming innovative standards, methodologies and culture in education. Blended learning means that percent of the class is delivered digitally. Entirely online classrooms deliver all the content virtually. The virtual or partly virtual courses vary significantly from face-to face experience and require specific design to get the same or improved learning outcomes. The role of course designers is primarily accomplished by the teachers, researchers in the field of education, or instructional designers. One of the examples of blended learning designs is flipped classroom. Jonathan Bergmann and Aaron Sams coined the term flipped classroom in 2012 [1]. It is a reverted to traditional form of teaching, where

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the lecturing part is distilled in the form of video before the class, whereas in class time is devoted to activities [1].

Successful conceptual design is a first step toward innovation in design [2], therefore to approach the invention of new classroom designs creatively, the systematic-creativity tool was used. The provided case study is aimed to thoroughly investigate TRIZ ideas generation in the educational field to find ideas of new or improved classroom design types. Prime research question is: “How TRIZ can be helpful in ideas generation for new classroom development?” Additional research questions are “How these ideas respond to the TPCK education theory?”, “How the concepts can be implemented and evaluated and “What are the basic results of their implementation?”.

Theory of Inventive Problem Solving (TRIZ) is a systematic creativity tool, aimed to idea generation. Defined concept of creative thinking rooted in the work of Genrich Altschulller in 1956 [3] and the term appeared in 80th. The homecourt of TRIZ is Mechanical design [4] and currently it dominates in reports on the applications of the method.

The chapter adds to the use of TRIZ for education design. It focuses on the teaching classroom design concepts development. Idea generations for classroom designs requires justification in terms of educational effectiveness. Thus, the developed concepts are described in terms of Technological Pedagogical Content Knowledge (TPCK) framework. Some of ideas are implemented within course of “Systematic Creativity and TRIZ basics” at Lappeenranta University of Technology and the feedback of participants and data from learning management systems and video hosts are used as experiment results.

2 Background

Let us first briefly tell what is inside of TRIZ. The term “theory” is not really applicable to this collection of tools to stimulate the design of new concepts. These tools are non-uniform, overlap, need proper application of Occam razor as well as evidence based proofs of efficiency and scientific discussion. However, comparing to other competitors in the market of creativity support, it seems to be much closer to its name. In addition to extremely positive response from the practice, it has specific features of a theory: modelling techniques, the formalism over the models and a number of criteria to compare ideas. For example, TRIZ can model a situation that requires an inventive idea by contradictions. Having formulated the contradiction in generalized from one can get from TRIZ a number of principles to eliminate it or to change the design in such a way that conflicting requirements are separated. This is fundamental difference to natural intention of designer to commit a compromise. If ideation yielded several design ideas, there are reasonable fitness axioms to compare them like Ideality or Dynamization increase concepts.

One of the modern TRIZ modelling tools is Function analysis. It presents a system as a number of interconnected elements, linked to each other by functions.

Function between two components is legitimate if components are material objects, which interact and parameter of the Function recipient is maintained or changed as the result of function [5], where Function Recipient is an affected component. Having modelled a system by Function model (that sometimes need even research efforts) one can apply Trimming tool to reduce its complexity or Contradictions elimination tool in case harmful functions also detected in the model. Trimming is generally used for elimination of the elements within three main rules: elements which are not necessary, which can be substituted or which function, can be delegated to other elements [5]. Contradiction elimination by TRIZ is assessment of two isolated requirements, where one is an improving parameter and another is worsening. Ideal Final Result is a core concept of TRIZ, leading to more radical and creative ideas than others, since the invention with IFR can be realized without functional model. The formulation is “Ideal system is no system but the function is performed when it is necessary and where it is necessary” [5].

Therefore, there are two approaches for conceptual design of something new by TRIZ. First, approach is to start from the scratch and to generate ideas for new design. It means that there are only recommendations, specification and requirements to be met by the new design. Something completely new is to be invented. Regarding the classroom design, for example. The inventive ideas can be generated with IFR (Fig. 1). The second approach departs from a functional model of the prototype system and TRIZ is applied to modify already existing design. Function models comprise basic tradition classroom and flipped classroom. Contradictions elimination is used for both models. Trimming is applied only for flipped classroom improvement (Fig. 1).

The term “Learning design” refer to the modeling learning experience. Learning science combines different fields among which are education, computer science, design science, neuroscience [5], systems engineering, conceptual design and others. One of the standard and generally accepted by educational institutions designs is traditional classroom, where passive in-class lecturing plays a main role. Sometimes it is combined with or followed by face-to-face exercises, laboratories, discussion and other types of activities, however activities are generally moved to the home-work. As blended and online learning (e-learning) concepts came to the stage quite

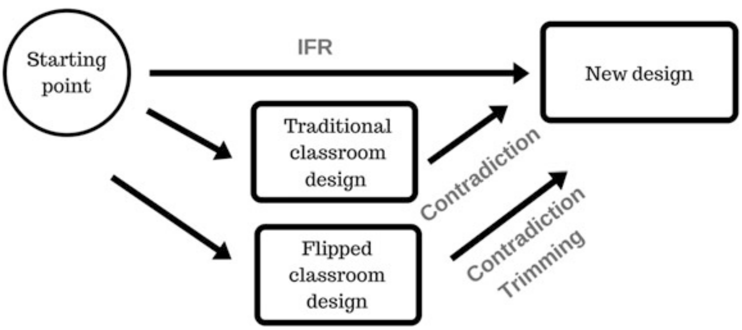

Fig. 1 Two approaches for conceptual design via TRIZ

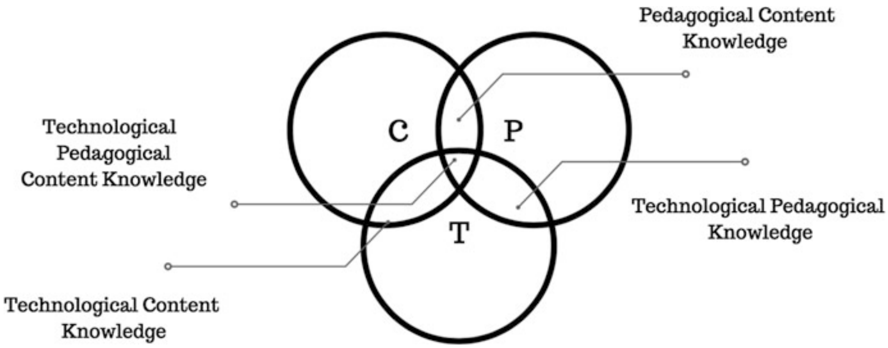

Fig. 2 TPCK model [7]

recently, their designs vary significantly, their forms, standards and guidelines are the subject of intensive discussion. One of the described blended learning designs is flipped classroom, where the class time is devoted to the activities and the lecturing part is moved outside the class in the video form [6].

Extended by technology Shulman's conceptual model of "pedagogical content knowledge" frameworks the representation and justification of educational designs [7]. Historically, teaching was focused only on pedagogical and content knowledge and pedagogical content knowledge (PCK) as an interaction of them [8]. Mishra and Koehler enlarge Shulman's theory by technologies, based on the 5-year design experiments [7].

Each part of the technological content pedagogical knowledge framework defines and testifies the elements of teaching process and interactions between them (Fig. 2). Content knowledge relates to the teaching subject whereas, pedagogy is a knowledge about processes and methodologies. C-P interaction is a harmonized method for teaching specific materials or "teaching approaches that fit content". Technology knowledge is the information on existing tools and solutions and their implementation. Technological content knowledge include primarily representation tools for the specific content. Technological pedagogical knowledge represents the teaching settings. TPCK is an interaction between three components [7].

3 Methods

We address the research questions by the case study research, in which Contradiction analysis, IFR, Function modelling and Trimming are used for the generation of ideas and concepts for innovative learning design. Most of generated concepts are given in the course on Systematic Creativity and TRIZ basics in Lappeenranta University of Technology. The surveys and observations are collected and analyzed to quantify the evaluation of new learning design.

Thus, the case study consists of 3 main steps:

1. Ideas generation via TRIZ (Function definition, Function modelling, Trimming, IFR, Contradictions Elimination)
2. Ideas evaluation via TPCK model
3. Ideas justification within real course design experiments

4 Case Study: Conceptual Learning Design Generation via TRIZ

4.1 Function Definition and Modelling

Formulation of function for the "learning design" straight depends on the definition of the core competences. For instance, in Lappeenranta University of Technology the core competencies are skills, experience and attitude. Therefore, the function is to transfer knowledge to students, develop skills and attitude. The function is the same for any type of teaching classroom, including traditional classroom, flipped classroom, virtual classroom or any other combination of teaching units. According to that, the component model (Fig. 3) is going to have four level hierarchy, where on the first level is any learning design, on the second knowledge transfer part, and skills delivery part. More specific components are on the third and fourth level. The standard teaching elements are lectures and different types of activities, including seminars, laboratories, group works and etc. Primary function of the lecture is to deliver a knowledge, whereas seminars and activities are aimed to develop student's skills.

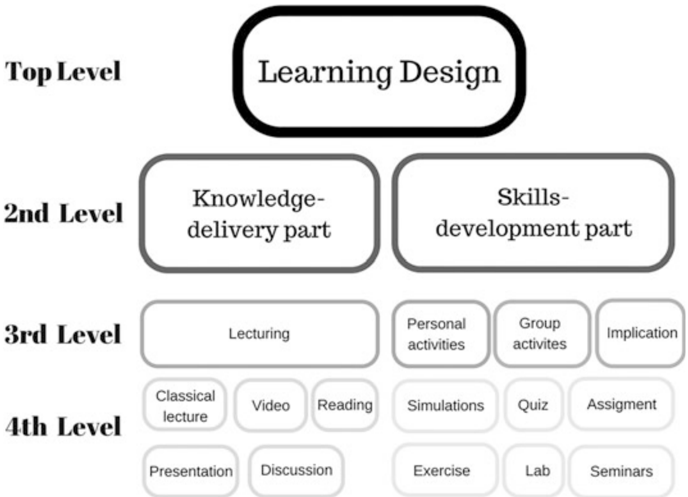

Fig. 3 Component model of learning design

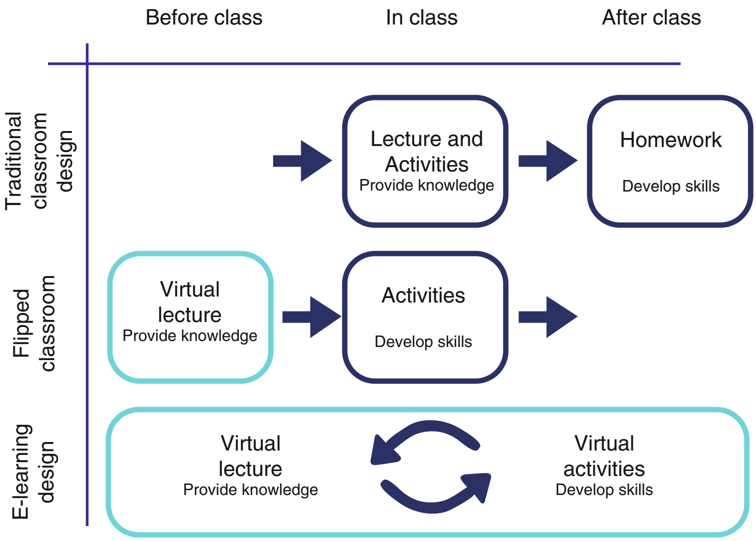

Fig. 4 Basic learning process concepts for traditional, flipped and online classroom

A simplified process flowchart for traditional learning class, flipped class and virtual one are described in the (Fig. 4). The two main functions are mentioned on each class design for each component. Knowledge transfer is followed by the skills transfer in each case.

4.2 Trimming

Starting from functional model of the teaching classroom design, the system can be simplified by TRIZ trimming exercise. It yielded a model with *complete lecture elimination*. In the case of flipped classroom, traditional guided online or offline lecture disappears. Instead, guidelines and requirements are formulated by teacher for activity preparation. According to trimming rule, that says that a function carrier can be trimmed if another component performs its useful function, the knowledge transfer in this case can be accomplished by *students' self-study with selection and learning process guided by students* (Table 2).

In the age of increased amount of information, learners can find a lot of valuable, high quality content for the defined topic. Whereas, the limitation by the personalised teacher's lectures and books seem impossible. For instance, if the basic course of math is already taught by some other teacher in open source and public strongly appreciate and recognize it as a valuable material. From pedagogic content knowledge the shift from teaching methodology to guiding methodology, change the way of pure lecture content consumption. Alongside with that, giving more freedom to students in finding the content for getting required knowledge and providing more opportunities for self-study allow to make learning more flexible, with increasing responsibilities of learners.

4.3 *Ideal Final Result*

Application of TRIZ IFR concept leads to the following conceptual models:

- Ideal teaching classroom is lack of the teaching classroom but knowledge is transferred, experience is gained and attitude is perceived, when it is necessary and where it is necessary
- Ideal lecture is no lecture but the knowledge is transferred and attitude is perceived
- Ideal activities are no activities but the experience is gained and attitude is perceived

The way to ensure the system without its existence can occur if everything happens itself. In that case, there is an idea of *completely independent way of study*. When students study by themselves, they use huge range of open materials, which include not only *passive lectures but also activities*. The prepared online *courses like MOOCS (Massive Open Online Courses) or combination of different knowledge* from video, chats, discussion forum can be used as a teaching materials. Digital technologies provide access to the content, and communication supports self-study without loss in quality. Pedagogy of self-study emphasizes the lowered motivation of students without face-to face activities. In a way, self-study would be more ideal if the environment is a source of stimulation. Consequently, *an automotive guide, as your personal teacher, analyses enormous amount of information and selects the learning path, according to your interests and needs*. For instance it could be selection of materials by keywords or hashtags. Harmonization of external and internal motivation lead to constant learning and improvement (Table 2).

Practically, in Lappeenranta University of Technology, the *video lectures were developed using the most-resource effective ways*. Thinking, with IFR result, ideal camera is no camera but the function is performed, ideal studio is no studio and etc. For instance, phone instead of special camera and special equipment were used. https://www.youtube.com/channel/UCqr4R5hyHjs1ve-4znD0asQ. In addition, moving toward ideality, free learning virtual space for students were selected. The videos, quizzes, texts, slides, examples and other materials were gathered on the free-charged platform with open access for unlimited amount of students. http://triz.thinkific.com/courses/triz. The concept of instant feedback system were developed involving IFR. The system according to Ideal Final Result is no system but the questions, comments and mood is transferred to the teacher. The prototype allows students to ask questions without professors' interruption and the questions are posted in the window of presentation, above other windows. The one of the versions is published here http://askbox.strikingly.com/ and approached in different classes.

4.4 Contradictions

Based on the functional model of "learning design" we can observe the traditional, blended and virtual classroom as a list of contradictions. The list of contradictions is built based on the professors and students' barriers in different classroom types [9–11] and observations within the Lappeenranta University of Technology environment. Table 1 below consists of contradictions, described by the worsening and improving parameters, inventive principles and generated ideas. Overall, worsening parameters involve four main categories: resource related, pedagogical, including instructional designs and evaluation approaches, content, administrative and technological issues.

For eliminating contradiction, 40 inventive principles were reviewed, selected and adapted for the non-engineering system of learning design (Table 1).

Primarily, the ideas are formulated based on contradictions elimination toward improved flipped and virtual classroom conceptual designs. Main pedagogy behind the flipped classroom methodology is freeing time for activities, increasing communication, involvement, personalization and other learning parameters [12]. In addition, structural change allow to make class more flexible, adapt it to the different learning styles, familiarize with information beforehand. Therefore, students can get deeper understanding of materials and gain more practical learning experience. Due to combination of technology and content the lecture part become digitized. The active part can be embedded by using feedback system and activities. To increase the time for activities the video part can be separated from the class. To simplify and improve video materials selection and development, the Inventive TRIZ principles lead to ideas of using the materials of others for instance of colleagues. In addition, students can search and add the materials in the collection. In different cases, the video can be developed or selected by professor. Overall, innovative learning designs create more student-centered learning approach.

4.5 Overview of Generated Ideas and Their Implementation

The ideas and concepts developed with TRIZ method were realised in Lappeenranta University of Technology. The traditional course of "Systematic Creativity and TRIZ basics" was redesigned to partially flipped, flipped and online courses in

Table 1 Contradiction elimination

Improving parameters	Worsening parameters	Inventive principles	Solutions
Traditional classroom design			
Classroom digitalization • Speaking the same language with students • Following the development of the surrounding environment • Digital space for communication	Disturbance of the student's attention Learning new skills and methodologies	Principle 22. "Blessing in disguise" or "Turn Lemons into Lemonade"(Turn harmful function into benefit) Principle 24. Intermediary	Use phones for answering quizzes and giving feedback, rather for destruction Use the learning management systems, video hosts, social networks for communication
More free time for seminars and activities	Class time increase Student workload increase Professor's dedicated time increase Credits and administration of the course	Principle 1. Segmentation Principle 2. Taking out Principle 10. Preliminary action	Separate the lecture from the class by making it outside the class in a video form Put the lecture before the class
		Principle 3. "Local quality" Principle 28. "Mechanics substitution" Principle 35. "Parameter changes"	Change the object structure and substitute the mechanics to digital
Increase student-teacher interaction (personal time, communities, involvement)	Increased class time (dedicated time) Decrease of lecture time (lack of information)	Principle 23. Feedback Principle 32. Color changes	Introduce the feedback system to improve lecturing Use the materials with the changing colors to increase personality
Flipped classroom design			
Video lecture as a part of flipped classroom • Developed by professors • Selected from the internet	Increase of devoted time Ineffectiveness Low quality of materials Not adjustable and Not Relevant Need for new facility and facility usage	Principle 5. Merging principles allow to bring closer objects Principle 25. Self-service (make an object serve itself)	Find and use lectures and materials of others Students search for and create the materials for the collection

(continued)

Table 1 (continued)

Improving parameters	Worsening parameters	Inventive principles	Solutions
Increased amount of video views before the class	Creating the extra control forms (like quiz) Increased time	Principle 6. Universality Principle 5. Merging	Merge the video part with questions. The function of video become to provide knowledge and control their accomplishment
Increase the video quality	Increase of time Professional training	Principle 24. Intermediary	Involve professionals or students in the field
Online course design			
All materials uploaded on the online platform	Creating and transition of materials to new platform	Principle 1. Segmentation	Connect of already existing materials in one open platforms
Increase of the communication with teacher and increase of teacher presence in the virtual environment	Increased burden on teacher and time required	Principle 15. Dynamics	Automatic response from the system
Increase of the communication between students	Increase of guidance and time required from teachers	Principle 15. Dynamics	Conditions for the cross communication
Increase of the online platform participation	Increase of time by the amount of reminders	Principle 35. Parameter changes Change the flexibility	Play with flexibility of the guideline (deadlines for modules) Make them more synchronous or asynchronous

2016, 2017, 2018, in accordance. The Table 2 presents all ideas generated in the case study, TRIZ tools used and their implementation in real courses. Worth mentioning, that the new course design ideas came not solely from TRIZ, but were also extracted from literature review and practical experiments. Therefore, some of the ideas developed in this case study appear repeatedly.

4.6 Course Designs and Implementation Roadmap

The ideas influenced the course redesign for a number of years in which the course was taught. Five different designs of the same course are described in Figs. 5 and 6.

Table 2 Ideas and their implementation

No	Idea	Generation TRIZ toolkit/ Course type	Implementation
1	Develop feedback system	IFR, Contradictions	Implemented in partly flipped course 2016–2017
2	Find resource-effective approach for video recording instead of resource required (lean, TRIZ approaches)	IFR	Implemented in courses in 2016 (for creation video materials)
3	Separate the lecture from the class by making it outside the class in the video form	Contradictions Traditional design	Implemented in partly-flipped course 2016–2018 online courses
4	Change the object structure and substitute the mechanics to digital		
5	Use the materials with the changed colors		
6	Merge the video part with questions	Contradictions Flipped classroom	Implemented in flipped classroom 2017–2018
7	Find and use lectures and materials of others	Contradictions Flipped classroom	Implemented in online course 2018
8	Play with flexibility of the course temp (Synchronous/asynchronous)	Contradiction Online course	
9	Connect of already existing materials in one learning management system	Contradiction Online course	
10	Use learning management systems, video hosts, social networks for communication	Contradictions Traditional design	
11	MOOCS (Massive Open Online Courses)/online course	IFR	Implemented as online course developments 2018
12	Students search for and create the materials for the collection (Alongside with learning)	Contradictions Flipped classroom	Partly implemented in online course (exercise to share brainteasers from students)
13	Eliminate lecture (Flipped classroom without lecture) (a) Substitute lecture with guidelines and requirements to activities (b) Self-study guided by students	Trimming	Not implemented (transformed but not completely eliminated)
14	Completely *independent way of study*	IFR	Not implemented
15	An automotive materials selector and guide	IFR	
16	Use phones for answering quizzes and giving feedback rather for destruction	Contradictions Traditional design	

(continued)

Table 2 (continued)

No	Idea	Generation TRIZ toolkit/ Course type	Implementation
17	Involve professionals or students in the field	Contradictions Flipped classroom	
18	Automatic response from the system	Contradiction Online course	
19	Conditions for the cross communication	Contradiction Online course	

Duration of the course is 78 h which is equal to three credits. From 2011 to 2015 there were practically no significant changes in a course design in terms of structure. The first attempt to re-arrange course took place in the Summer school 2016. The preparation video materials were developed and integrated. The feedback system was tested. First experience and feedback analysis revealed that the video contents require more control elements and extra preparation materials. The design was enriched by quizzes and other learning materials gathered together on the open e-learning platform (http://triz.thinkific.com Winter school 2017). However, students reported the increased workload for relatively short intensive course. In addition, the gap between online and offline environment was revealed: there was no clear navigation between what had been taught in class and presented as self-contained offline teaching materials.

For Summer school 2017, the flipped classroom model was fully implemented, the video part was arranged with embedded questions using EdPuzzle and in-class part was activated. The students were randomly grouped in four teams. Each team was supported and mentored by a PhD student. The teamwork consisted of different activities, like generation of ideas, quizzes, games, role changes, cases and others. To bridge the preparation part outside the class and in class part discussion opened every class day. Pure lecturing part was practically eliminated. According to the observations, surveys and other learning analytics, the most successful was embodiment of flipped classroom (Fig. 5).

The data was collected through classroom observations, student's questionnaires, scores tracking, specific experiments and learning analytics from learning management system, video host, communication channels. Questionnaire forms primarily include the qualitative questions related to students' satisfaction with respect to the design elements. Students feel more involved and motivated with the better understanding. Familiarization with video materials in advance make all students more open for discussion. Involvement of activities within the summer school 2017 provide more benefits. While increased time for activities and four mentors, lengthen the personal communication, avoiding free riders in the class. In addition to it, learning analytics from platforms provide an information about possible course design improvements within all the experiments. For instance, the problem of low

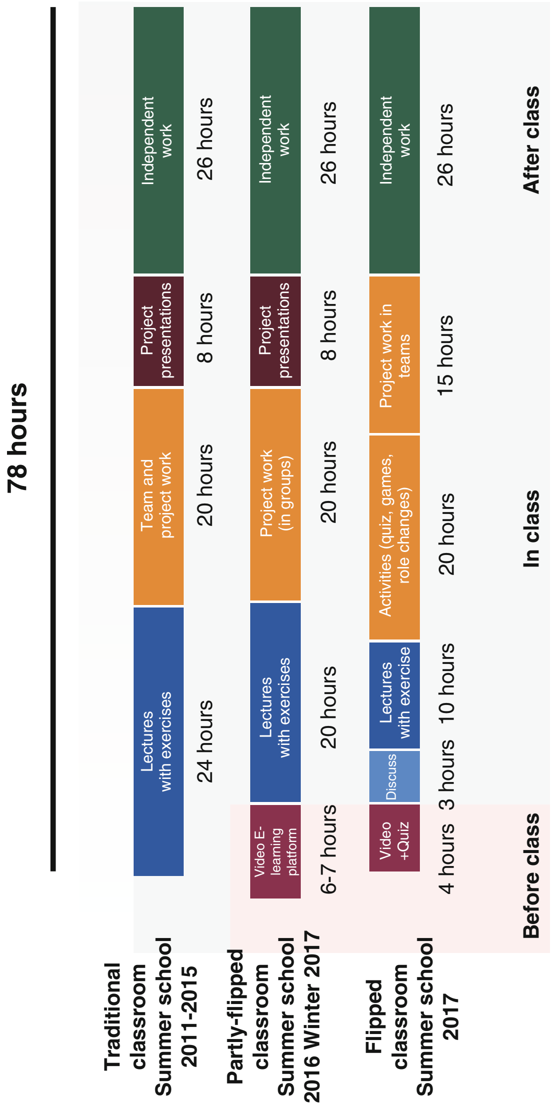

Fig. 5 Course designs from Traditional to Flipped

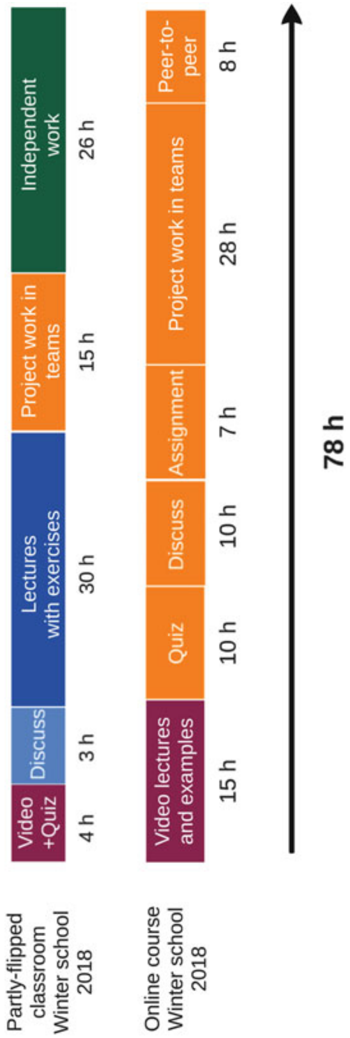

Fig. 6 Course designs from Traditional to Flipped

video views was solved using specifically designed quizzes and shared in advance videos. The main results after each course re-design reveal positive feedback from most of the students [13] and resource-effectiveness of developed flipped classroom design [12].

The last experiments of the same course re-design were conducted during Winter school 2018 (Fig. 6). The session of partly flipped classroom went alongside with online session. The students from partly-flipped classroom 2018 had the same preparation part as flipped 2017 and in class part was the same as partly flipped 2017 (Fig. 5). The online winter school course 2018 started at the same time and was arranged in the separate learning management system triz.thinkific.com. In order to increase student motivation, involvement and to satisfy the needs of the master students, online course mainly consists of activities with the short preparation materials. The online activities involve quizzes to control the video views, discussions related to the topics, assignments, web-meetings and project work with the initial peer- to- peer review. The evaluation of the results is currently in the process.

5 Conclusions

The paper presents results on application of guided ideation exercise on conceptual redesign of university course. The theory for inventive problem solving, TRIZ, was the main tool for analysis and ideation. The quantitative design ideas were described in the framework of Technological Pedagogical Content Knowledge (TPCK) model. The application of new learning concepts was supported by a number of digital tools that could be referred as eLearning. The changes engaged videos and instant feedback system, learning platform development. Several years journey (2016–2018, course “Systematic creativity and TRIZ basics” at Lappeenranta University of Technology) from traditional class organization to flipped classroom and e-learning design is described. The results of students feedback, which are described in the previous studies are mentioned and generalised in the chapter. The course in summer school 2017 was the best example of successful flipped classroom design according to the student involvement and satisfaction. The results of the just recently emerged flipped and online classrooms of 2018 are currently in the progress.

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Experimental Validation of Quantum-Economic Analysis (QEA) as a Screening Tool for New Product Development

Oleg Abramov, Sergey Markosov, and Alexander Medvedev

1 Introduction

The Quantum Economic Analysis (QEA®) theory was originally developed as a tool for business consulting by Shneyder, Katsman and Topchishvili [1] and further advanced by Topchishvili, Malkov and Tunitsky [2].

QEA states that if a business is to be successful, the combined levels of development of (1) the company, (2) its product, and (3) the target market (further referred to as Combination) must fall within the set of "allowed" Combinations (further referred to as Allowed Set) that the authors of QEA derived by analyzing numerous business cases. If a business's Combination is not within the Allowed Set, it will unlikely be successful regardless of how good the company and the product are and how big the target market is. The authors of the QEA theory claim that it is "a powerful tool for devising brand development strategies" [3].

This approach allows business consultants to identify the right business strategy, as shown in the recent book by Khlebnikov, Alperovich and Yatsina [4]. For example, QEA helps to identify what changes to the company are needed in order to create a Combination that falls within the Allowed Set, and thus maximize the probability of business success.

One of the co-authors of this chapter has suggested [5, 6] that QEA with some minor modifications may be applicable not only in business consulting, but in technical TRIZ-consulting as well, albeit for a different purpose. In TRIZ-consulting, QEA may serve as a screening tool for new product development (NPD). As shown in Fig. 1, this tool can be used several times in the TRIZ-assisted Stage-gate NPD process [6] in order to reject unpromising ideas and prototypes whose Combination does not fall within the Allowed Set.

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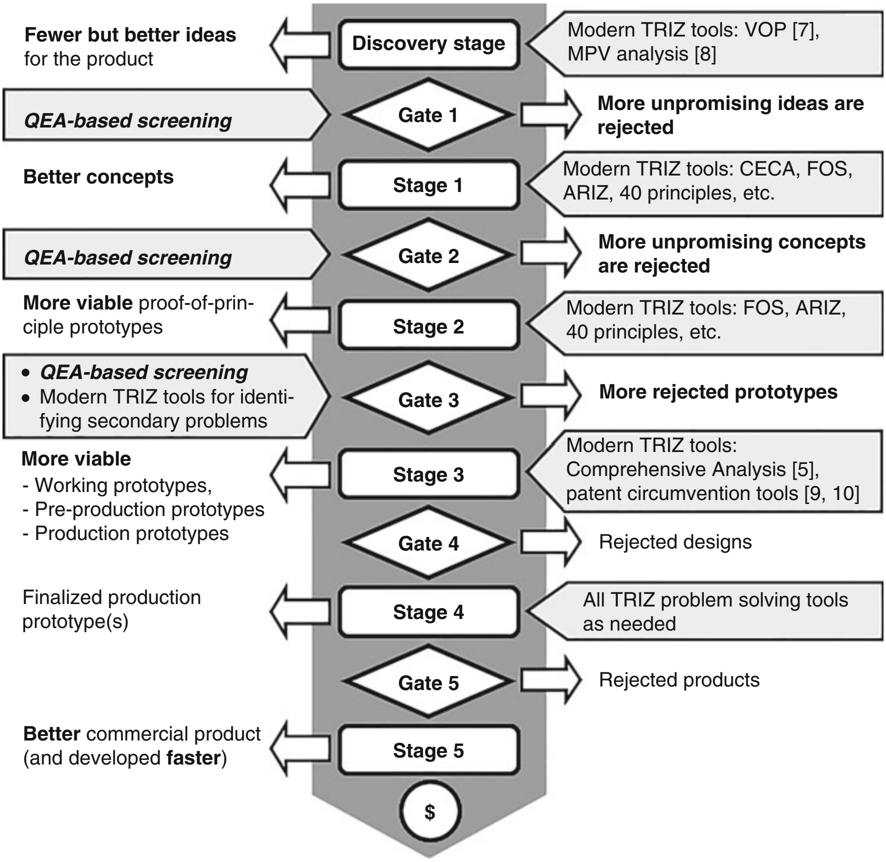

Fig. 1 TRIZ-assisted stage-gate NPD process that includes QEA-based screening [6]

Before using QEA-based screening in the NPD process, however, the Allowed Set must be re-validated: the authors of QEA based the Allowed Set on a number of business case studies that did not necessarily involve the development of a new product. Therefore, it is not clear, whether the original Allowed Set is applicable to NPD.

Additionally, many TRIZ-consulting projects are aimed at improving the manufacturing process or manufacturing equipment used to produce an existing product, rather than developing a new product. In such cases, the product itself may remain unchanged, making the original QEA inapplicable for evaluating ideas generated during these projects.

So, for projects aimed at improving manufacturing processes or manufacturing equipment, one of the co-authors has proposed [6] to adapt QEA by using the technology, or equipment, level of development in QEA-based screening—rather

Table 1 Objects whose development levels must be used in QEA-based screening

What is under development	Objects whose development levels must be used		
	Product (P)	Company (C)	Market (M)
New product	New product	Company	Market for the new product
New technology/equipment for manufacturing existing product	New technology or equipment	Company	Market for the existing product

than the product level of development (see Table 1). The viability of this approach must also be validated.

In this chapter, the authors have tried to validate experimentally QEA's Allowed Set for new products, manufacturing technologies and equipment by analyzing a pool of technical solutions that were developed for different companies in actual TRIZ-consulting projects.

2 Method

In order to validate the Allowed Set as a tool for selecting the most promising solutions and rejecting unpromising ones in TRIZ-consulting projects, the authors have analyzed the outcomes of technical solutions from a wide range of projects in which they were involved.

It is important to note that all of these solutions were substantiated and proven technically feasible prior to delivering them to the clients. The substantiation was done either by computer simulations or by building a proof-of-principle prototype. Also, the clients appreciated and accepted all of these solutions.

For each solution the authors tried to (1) ascertain whether the solution eventually yielded a commercially successful product, and (2) identify the Combination. Then they calculated both the percentage of "successful" solutions that met QEA's Allowed Set and the percentage of "unsuccessful" solutions that did not meet the Allowed Set.

The Allowed Set introduced by QEA is shown in Fig. 2.

As can be seen from Fig. 2, the development levels of product, market and company are actually three dimensions describing the current state of a business. Further in this paper we will call this a QEA Business Cube.

The development levels of product, market and company were identified as suggested in QEA [1]. Characteristics of each level are given in Table 2.

Note: for the projects aimed at improving manufacturing processes or manufacturing equipment, the authors used improved process or equipment level of development, instead of the product level of development, in the Combination, as described in Table 1.

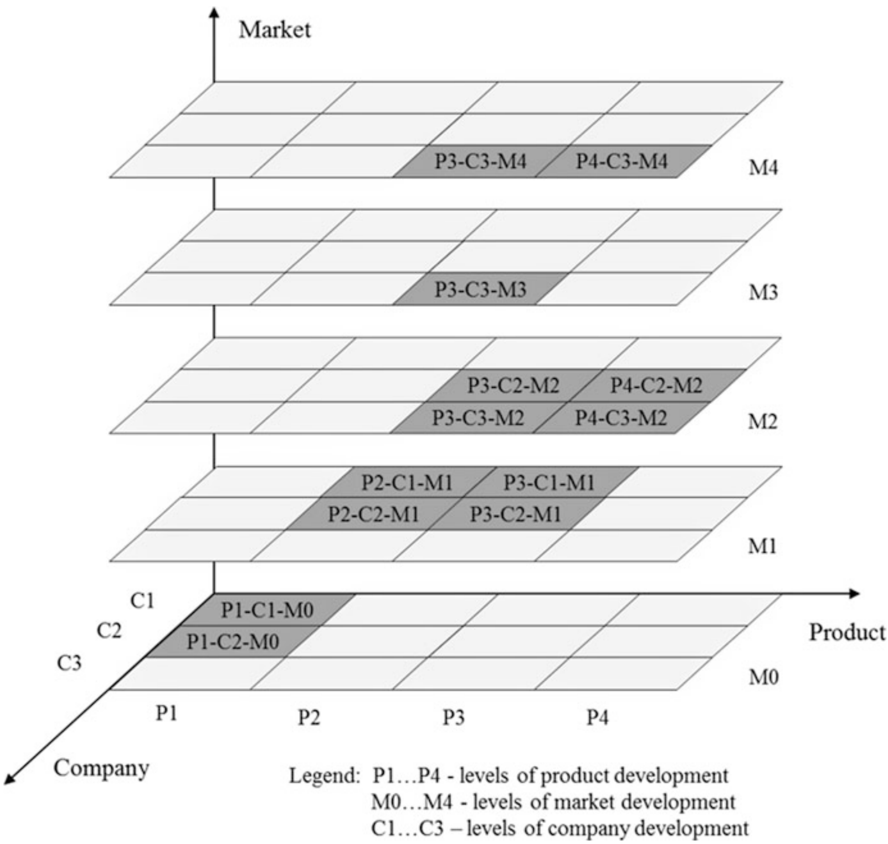

Fig. 2 The allowed set in the QEA business cube (see dark grey cells) [2]

Table 2 Characteristics of the product, market and company levels of development

Level of development	Development level characteristics		
	Product (P)	Market (M)	Company (C)
0	N/A	Very few consumers—early adopters only	N/A
1	Product level of development is determined as in regular TRIZ S-curve analysis, e.g. as described by Litvin and Lyubomirskiy [11]	New consumers appear, but they keep using previous product as well	Company can access up to $3,000,000 in capital
2		Mass consumer is switching to the new product, completely abandoning previous	Company can access from $10,000,000 to $100,000,000 in capital
3		All potential consumers are already using new product	Company can access over $100,000,000 in capital
4		Consumers are leaving the market and switching to a newer product	N/A

3 Results

In this research the authors analyzed a pool of 143 TRIZ-consulting projects in which they were engaged from 1997 to 2017. All of these projects were performed by Algorithm, Ltd. for different clients/companies representing a wide variety of industries.

From this pool, 114 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 over 400 feasible technical solutions that were delivered to the clients.

Of this number, the authors were only able to trace what happened with 42 solutions because often clients did not give feedback on whether the solutions delivered to them were actually implemented. Therefore, the authors analyzed the Combinations for only these 42 solutions. These include:

- 25 solutions aimed at developing a new product; and 17 solutions aimed at improving a manufacturing technology or equipment;
- 21 successful solutions, i.e. they were actually implemented, while the other 21 solutions were unsuccessful, that is they were either abandoned by the clients or the clients tried to implement them, but did not succeed.

Table 3 shows the distribution of the analyzed technical solutions across the levels of development of the product, market and company. The levels of development for each case were determined as described in Sect. 2 above.

Figure 3 shows how the 21 successful solutions are distributed within the QEA Business Cube. As can be seen from Fig. 3, all except three of the solutions fit into the Allowed Set.

Figure 4 shows how the 21 unsuccessful solutions are distributed within the QEA Business Cube. As can be seen from Fig. 4, almost all of these solutions, except two, lie outside of the Allowed Set.

Table 3 The distribution of the analyzed solutions across the levels of development of the product, market and company

	The number of analyzed solutions		
Level of development	Product (P)	Market (M)	Company (C)
0	N/A	4	N/A
1	23	9	7
2	9	9	8
3	10	15	27
4	0	5	N/A

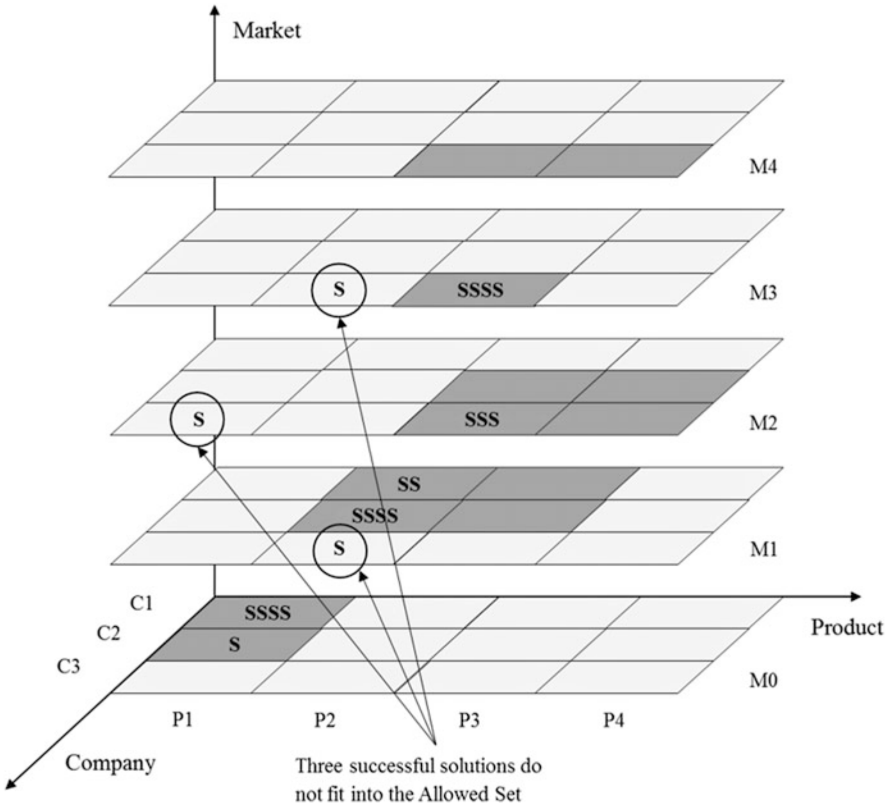

Fig. 3 Distribution of the 21 successful solutions (S) within the QEA business cube

4 Discussion

As can be seen from Fig. 3 and Fig. 4, (1) successful and unsuccessful solutions are essentially separated from each other within the QEA Business Cube, and (2) thirty-seven out of forty-two solutions fell into the "right" segments of the Cube, which generally confirms the validity of using QEA for evaluating technical solutions in TRIZ consulting.

An examination of the five solutions-outliers that did not fit into the correct Cube segments revealed the following:

- A successful solution that falls in cell P1-C3-M2 (see Fig. 3), which is outside the Allowed Set, can be considered successful only with reservation: this solution did yield a new product on the market, but it took a few years more than the company-client expected, and, therefore, by the time the product was launched, all major competitors had already introduced their own comparable products. So, this case could be considered 'an exception that proves the rule'.

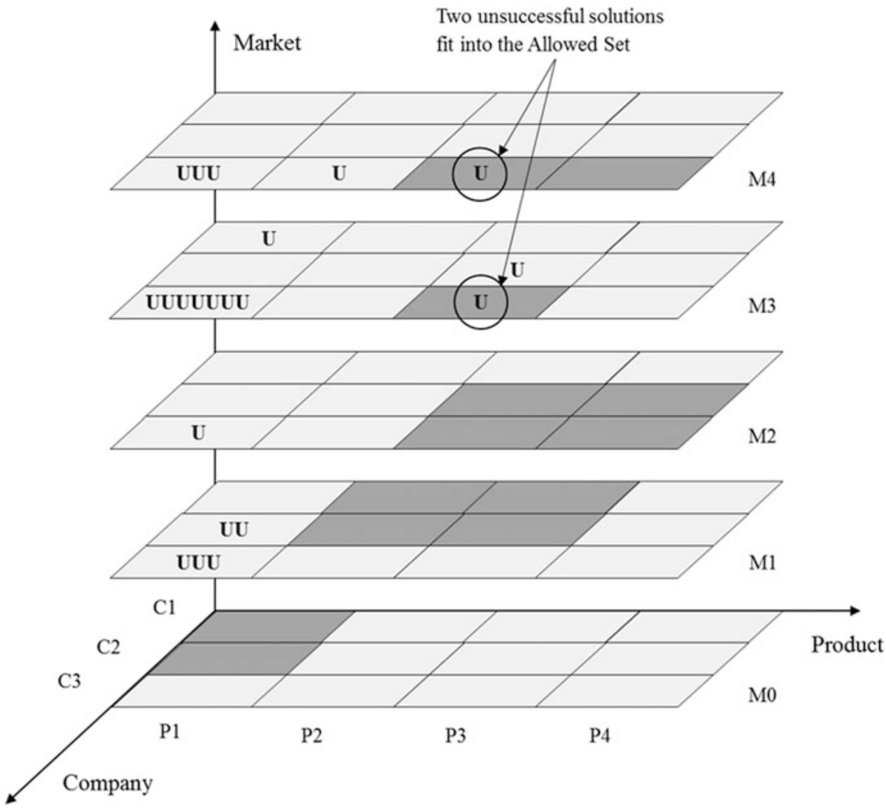

Fig. 4 Distribution of the 21 unsuccessful solutions (U) within the QEA business cube

- The other two successful solutions that do not fit into the Allowed Set on Fig. 3 relate to new technologies and equipment for manufacturing an existing product. This may indicate that QEA's Allowed Set has to be slightly refined to meet this specific situation.
- Both unsuccessful solutions that fall into the Allowed Set on Fig. 4, in fact, could have been successful: in one case it looks like the client just failed to develop a commercial prototype of the new product, despite the fact that TRIZ-consultants had developed and delivered to this company a working prototype of the product; in the other case, which relates to new equipment for making croutons, the client had planned to implement the solution immediately, but the entire top management of the company was suddenly fired and the new management abandoned croutons in favor of some other product. Neither of these cases, then, compromises the Allowed Set.

It has to be mentioned, though, that QEA should be further validated in order to obtain more representative statistics covering all cells of the QEA Business Cube.

The biggest challenge here is to identify which solutions have become successful and which have not, because clients are not always willing to share this sensitive information.

5 Conclusions

Based on the results of this research, the following conclusions can be made:

- Commercially successful and unsuccessful solutions are well-separated in the QEA Business Cube, which confirms that QEA's approach, indeed, can be used for evaluating technical solutions generated by TRIZ problem-solvers;
- All commercially successful solutions for new products fall into the existing QEA Allowed Set, while the unsuccessful do not, which means that this set may be used in NPD as is;
- The majority of successful solutions relating to technologies and equipment for manufacturing existing products fall into the existing QEA Allowed Set too. A small number of these solutions do not fit into the Allowed Set, which may mean that this set needs some minor modifications for such solutions.

The overall conclusion is that QEA, after slight modification, may indeed be included in the TRIZ-consultants' arsenal as a screening tool for evaluating the business potential of generated technical solutions.

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Can Altshuller's Matrix Be Skipped Using CBR and Semantic Similarity Reasoning?

Pei Zhang, Sarra Ghabri, Denis Cavallucci, and Cecilia Zanni-Merk

1 Introduction

Inventive Design recently appears as a new research field born on the basis that TRIZ [1] body of knowledge is promising and original, but also contains inconsistencies. The world-wide community of TRIZ, especially practitioners and researchers are constantly proposing ways of improving, reconstructing or merging it with other techniques in order to widen TRIZ potential scope of action. Within the scope of the TRIZ, various tools are proposed as the theory evolves [2]. Among them, the most widely known and appearing in chronological order include the 40 Inventive Principles, Contradiction Matrix, Substance field analysis and ARIZ (for the latter its evolution is true all along TRIZ history until 1985).

As a tool of the early times, Contradiction Matrix and Inventive Principles gained their famousness due to its simplicity of use, therefore their uses eases the access to TRIZ for newcomers. In literature, Invention Machine software took the Contradiction Matrix for resolving technical contradictions as an independent tool due to its simplicity of use by TRIZ beginners [2]. According to the survey of [3], the

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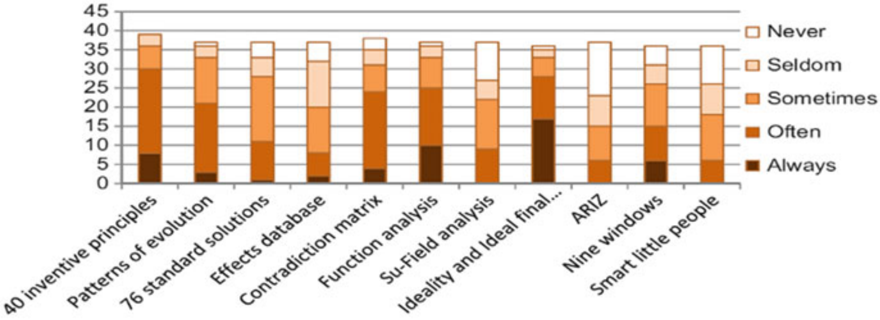

Fig. 1 Frequency of TRIZ method application (from [3])

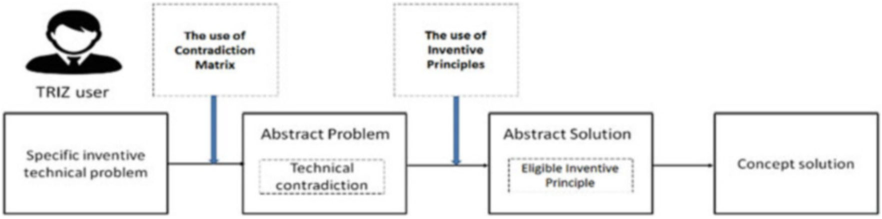

Fig. 2 The process of using Contradiction Matrix and Inventive Principles to solve a specific inventive technical problem

Inventive Principles and the Contradiction Matrix are ranked the first and the third most often used tools of TRIZ (Fig. 1).

According to classical TRIZ, the main process of using the Contradiction Matrix and the Inventive Principles to solve a specific problem is shown in Fig. 2. First, the abstract problem (which is a technical contradiction) is built in terms of two of the predefined 39 Generic Engineering Parameters (GEPs). Then, according to the Contradiction Matrix, the abstract solution (which is an eligible Inventive Principle) has to be selected among the statistically ordered Inventive Principles found in the Contradiction Matrix. Finally, the Inventive Principle is to be interpreted by users to transform it into an idea, candidate for being a solution (which we call a solution concept). The reliability of the problem-solving process relies on the two phases which are implemented manually. One is the linking between the specific problem and the abstract problem, the other is the interpretation between the abstract problem and the concept solution.

However, new users face difficulties in these two phases. For the first phase, new users have difficulties in associating contradiction's parameters to one or several of the 39 GEPs. Here, people describe their specific problems in natural language while the GEPs are generalized terms to describe a feature of engineering problems. For one generalized parameter, there are many ways to translate its meaning into natural language based on user's own understanding and perspective. Consequently, association between them is not intuitive.

For the second phase, new users have difficulties in interpreting the resulting Inventive Principles into concept solutions. Because the Inventive Principles only recommend a method for eliminating a certain type of abstract problem. Interpreting necessitates significant preliminary experience to react on the description of a principle and transform this information into a concept solution.

To improve these limitations, this paper introduces a methodology based on Case-based Reasoning coupled with the lexical similarity and the semantic similarity. It aims to help new users solve their specific problems by avoiding the use of the Contradiction Matrix and the interpretation of Inventive Principles. The implemented algorithm is based on the use of lexical and semantic similarity calculations proposed by [4]. The open source myCBR[1] software Development kit project is integrated into a web-based software demonstrator to facilitate the management of the case base, the manipulation of the similarity measures in the development of the application. With the use of our methodology, a new inventive problem is solved by retrieving past similar problems in appearance (the new problem and the old problems share similar words in description) and in meaning (the new problem and the old problems do not share similar words in description, but they have the same meaning) from the case base according to their similarities. The solution of the new case is constructed by adapting the retrieved solution.

2 Literature Review

To cope the difficulties in using the Contradiction Matrix and the Inventive Principles, many works have been done. One direction is to update the Contradiction Matrix or customize the Contradiction Matrix to narrow down its use in a specific domain. The work of [5] expands the 39 GEPs into 48 in order to make them more specific for the practitioners to use. The authors of [6] proposed the Contradiction Matrix and the Inventive Principles specifically for the semiconductor industry. The work of [7] indicates a promising direction to represent the biological strategies as the parameters to the Contradiction Matrix. The work of [8] proposed the generalized correspondences of human factor concepts of 35 out of 39 Generic Engineering Parameters to ease the use of Contradiction Matrix in manufacturing.

The other direction is the use of semantic technologies. One is to improve the accuracy of the mapping between the Specific Parameters and the GEPs [9]. In this work, the user has to define firstly his contradiction. Then, he selects one of the candidate GEPs that are semantically similar with the Specific Parameters of his contradiction. However, the users have a wide selection of words to describe their specific problems, the outcome of this method largely depends on the extent of accuracy of the specific parameter description. The other is to retrieve similar past

[1] http://www.mycbr-project.net/

solution cases according to functional semantics [10] with the aim of easing the implementation of the solution.

In conclusion, the existing methods ease the use of Contradiction Matrix and the Inventive Principles on some extent. As an research paradigm that has been adopted to reproduce human cognitive process for solving problems, the researchers started to point out the importance of combining Case-based reasoning (CBR) with TRIZ [10–12]. Therefore, we propose to avoid the use of the Contradiction Matrix in order to eliminate the existing problems in its use. Therefore, we propose to adopt Case-based Reasoning [13] (that contains four activities retrieve, reuse, adapt and retain) with Latent Semantic Analysis (LSA) [14] to exploit and [11] benefit from validated problem-solving experience.

3 Methodology

The proposed approach consists of five main processes based on Case-based Reasoning coupled with the lexical similarity and the semantic similarity calculation. It aims to eliminate the use of Contradiction Matrix to solve a new problem by adopting old validated experience.

- Problem description

In order to describe a new problem, different features are used. The input features (including the Element, Action Parameter, the value and its opposite value) and retrieval features (including the Evaluation Parameters (EPs), one is degrading while the other is improving) are useful for describing a specific problem (contradiction).

- Appearance retrieval

Once the new problem is correctly stated, we can retrieve the old problems that are similar in appearance by calculating their lexical similarities. To do so, we have first to apply the similarity functions on the new problem and the old problems. The similarity calculation between the new problem and the old problems is conducted in two levels. At the first level, the local similarity between the EPs are calculated by applying the Euclidean distance (Eq. (1)).

$$\mathrm{dist}\left(\vec{EP}_{old\ improving}, \vec{EP}_{new\ improving}\right) = \sqrt{\sum_{i=1}^{n}\left(\vec{EP}_{old\ improving}[i] - \vec{EP}_{new\ improving}[i]\right)^2} \tag{1}$$

where the two vectors representing respectively the $EP_{old\ improving}$ and $EP_{new\ improving}$.

The Euclidean distance is also applied to calculate the similarity between vectors representing the $EP_{old\ degrading}$ and the $EP_{new\ degrading}$. At the second level, the global similarity between the new problem and the old problem is calculated in order to depict the old problems similar to the new ones. To do that, we applied the weighted sums of the local similarities with the weights (0.5 assigned for each distance). As it is shown in Eq. (2).

$$dist(P_{new}, P_{old}) = \frac{0.5 * dist_{EPimproving} + 0.5 * dist_{EPdegrading}}{0.5 + 0.5} \tag{2}$$

where $dist_{EPimproving}$ represents the local Euclidean distance between a $EP_{\text{improving}}$ of P_{new} and the $EP_{\text{improving}}$ between a P_{old} whereas $dist_{EPdegrading}$ represents the local Euclidean distance between a $EP_{\text{degrading}}$ of P_{new} and the $EP_{\text{degrading}}$ between a P_{old}. The retrieved cases obtained are sorted by the similarity values in descending order [4].

- Semantic retrieval

The results based on the lexical similarity calculation is not always satisfactory. Because there are different ways to convey the same meaning using different words. Therefore, the specific problems that are similar in appearance do not bear the similar meaning. In order to find cases that are similar in meaning, we proposed the use of LSA to construct a geometrical semantic space and a physical semantic space with the aim of calculating the semantic similarity between the Evaluation Parameters and the terms in the semantic spaces [15]. Based on the retrieved Evaluation Parameters similar in appearance to the Evaluation Parameters of the new problem, we search for each obtained Evaluation Parameters, the similar terms in the constructed semantic spaces. For each found similar term, we run through the case base in order to identify the old cases that are similar in meaning to the new problem.

- Reuse

If the new problem is identical to the problem of the retrieved case, the old solution can be reused directly (reuse is also defined as null adaptation in [16]). If not, adaptation is required.

- Adaptation

There are different types of adaptation: transformational adaptation and generative adaptation. The transformational adaptation comprises two sub-types: substitutional adaptation and structural adaptation. Substitutional adaptation replaces some part of the retrieved solution by another. Structural adaptation alters the structure of the solution and reorganize the solution. Generative adaptation replays the method of deriving the retrieved solution on the new problem [16].

4 Case Study

In order to demonstrate the proposed method, we developed as a java web application called CBRID (Case-based Reasoning for Inventive Design). This system uses spring[2] as a framework for JAVA EE[2] web application. It was deployed in Tomcat 7[3] as the web container and connected to a MySQL[4] database that is managed by MySQL[4] server (version 5.7.14). Many other tools were used to establish CBRID such as protégé 3.04[5], Eclipse Juno[6], and MyCBR[1] workbench.

Based on the proposed approach, CBRID consists of five continuous processes illustrated by the data flow diagram in Fig. 3. The external entities representing the user and the semantic space. They are the objects that the system communicates. MyCBR project is composed of two repositories of data: the case base and the similarity functions. It is represented as the datastore notations. The five processes of the system are represented by the process notations which transform incoming dataflows into outgoing dataflows. These dataflows are represented by arrows.

The *user* describes his specific problem, the *Problem description* process receives the *Problem features*, forwards the *Retrieval features* to the *Appearance retrieval* process that accesses to *Case base* and *Similarity Function* datastores. The similarity algorithm is executed to retrieve the *Similar cases in appearance* and forwards it to the *user*.

The *user* sends *Semantic retrieval request* to the *Semantic retrieval process,* the *Semantic retrieval process* forwards the *Similar cases in appearance* to the *Semantic space*. The Se*mantically similar terms* are obtained from the *Semantic space* and returned to the *Semantic retrieval process.* A search algorithm is implemented in the *Semantic retrieval process* using the *Semantically similar terms* and accessing the *Semantic space* database and the *CASE-BASE* datastore to retrieve the *similar cases in meaning* to the user. The *user* selects the *selected case* that is identical to his new problem to the *Reuse* process. The *Reuse* process forwards the *old case* and the *PDF repor*t to the *user*. Otherwise, the *user* selects the *selected case* that he wants to adapt its solution to solve his new problem to the *Adaptation process*, the *adapted solution* is stored in the *Case base* datastore. The *Adaptation process* return the *new case* and the *PDF repor*t to the *user*.

A case study is given to illustrate these processes in detail. The recycling bins are commonly seen in public spaces. To keep the part of the bin sanitary, the plastic garbage bags are useful to line the insides of this part. To reduce the *plastic consumption*, the volume of the bin should be small to adapt it to smaller garbage bags. However, the volume of the bin should be also big at the same time to satisfy the *storage volume*. As it can be seen from Fig. 4, the user describes his problem by

[2]https://spring.io/

[3]http://tomcat.apache.org/

[4]https://www.mysql.com/

[5]http://protege.stanford.edu/

[6]https://eclipse.org/juno/

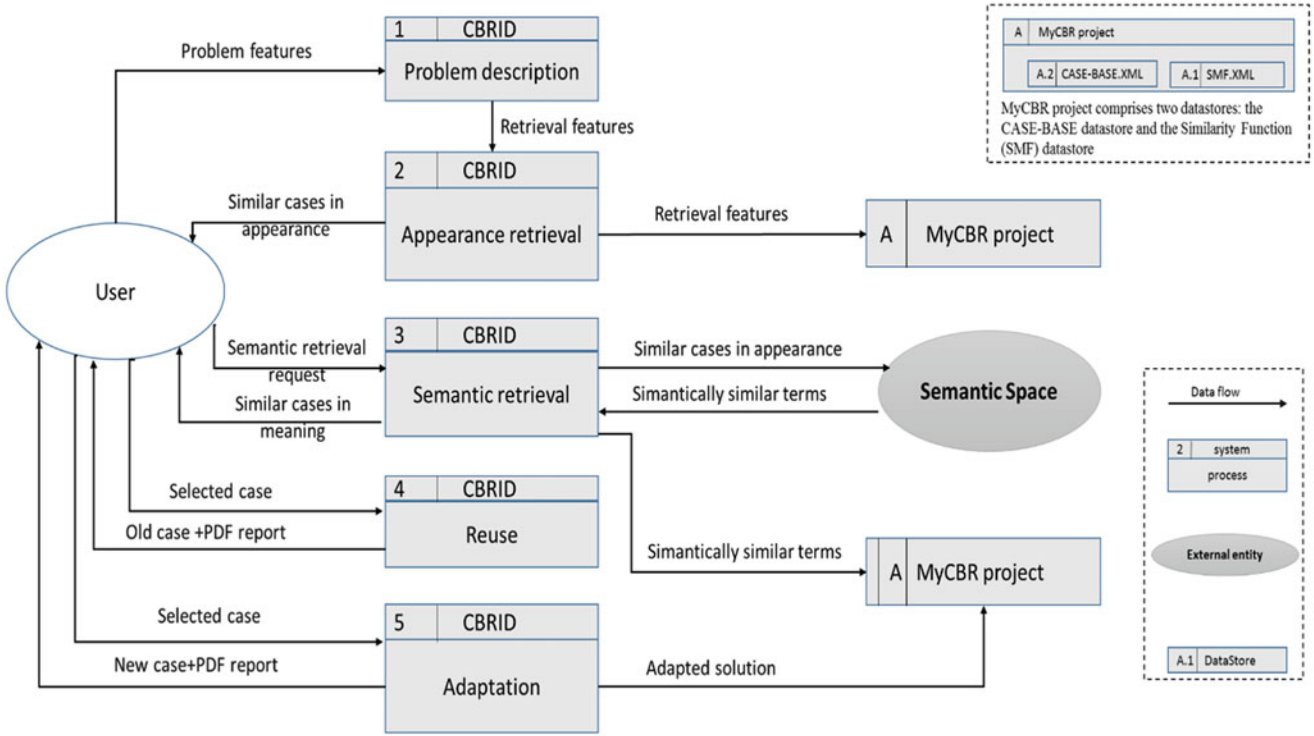

Fig. 3 The CBRID system data flow diagram of using CBR to solve a specific inventive technical problem

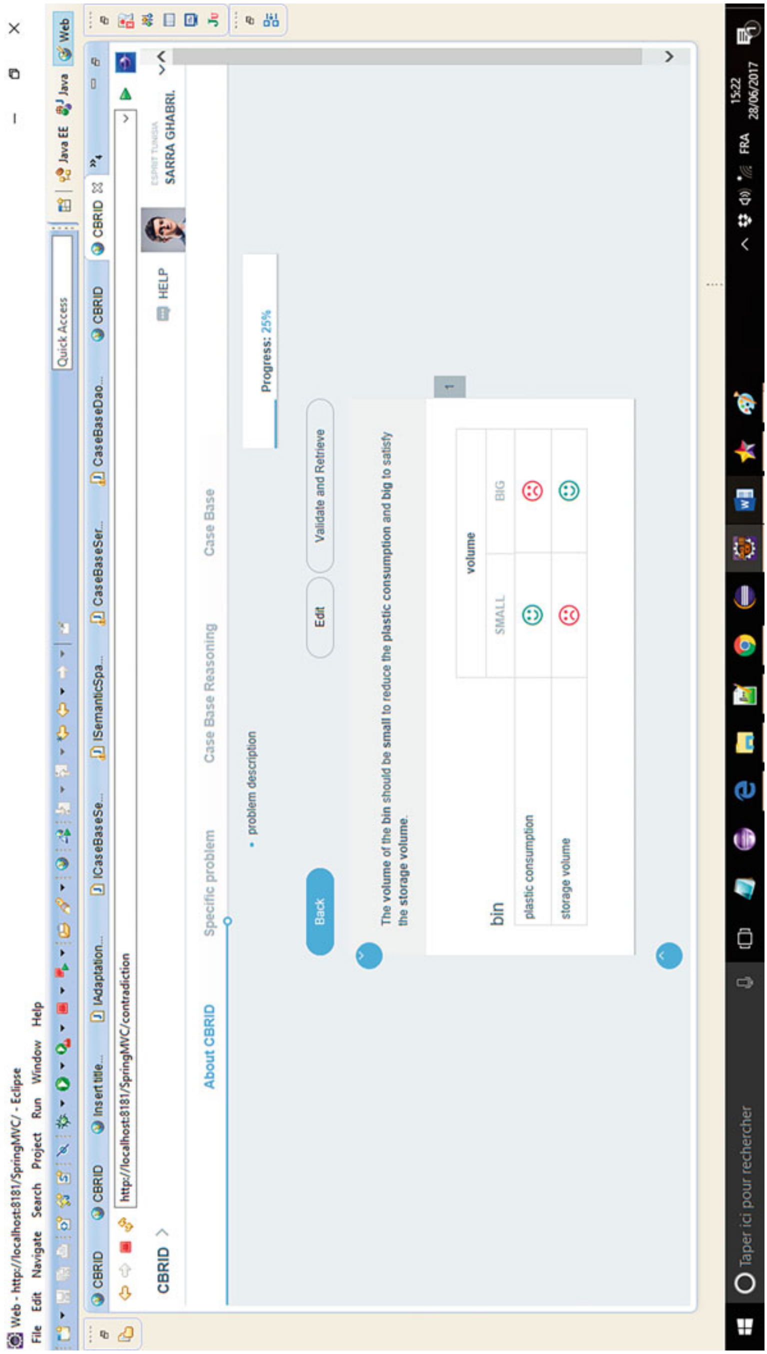

Fig. 4 The problem description of the "recycling bin" case

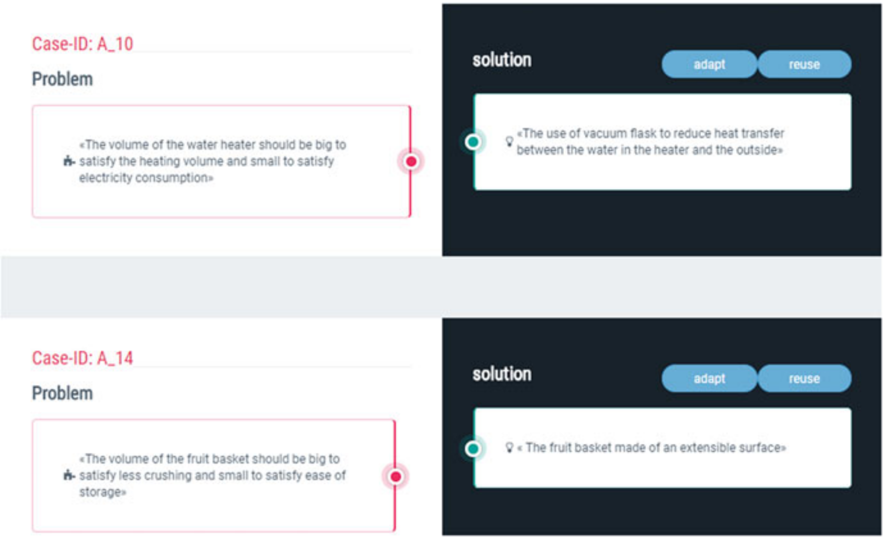

Fig. 5 The retrieved cases that are similar in appearance

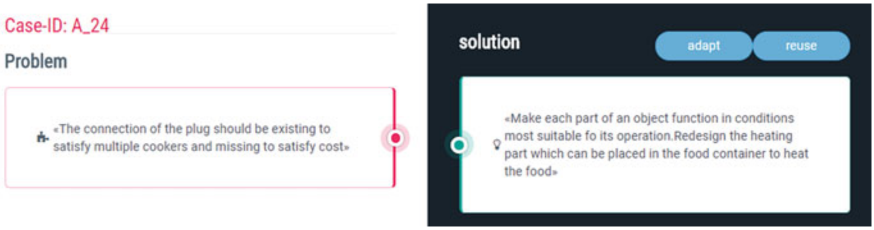

Fig. 6 The retrieved case that is similar in meaning

Table 1 Comparison of the retrieved cases

	SP degrading	SP improving
New problem	Plastic consumption	Storage volume
Old problems (similar in appearance)	Electricity consumption	Heating volume
	Less crushing	Ease of storage
Old problems (similar in meaning)	Less material	Multiple cookers

filling the table with features that describes the contradiction. Then, by clicking "Validate and retrieve", the previously mentioned process will be applied. Therefore, we get two results: the cases that are similar in appearance (Fig. 5) and the cases that are similar in meaning (Fig. 6).

As it can be seen from the second line in Table 1, the retrieved old problems share similar words with the old problem. However, specific parameters like "storage volume" and "ease of storage", they are similar in appearance but they are not similar in meaning. Applying the semantic retrieval, we are able to retrieve the case that is similar in meaning with its parameters “less material” and “multiple cookers” as it can be seen from the third line in Table 1.

Based on the retrieved similar cases, the user can choose one case that is similar to his new problem by adapting the old solution to solve it. The user can adapt the old solution in three ways: null adaptation (reuse the old solution directly); transformational adaptation (using the same IP and revise the concept solution or revise the solution entirely and generative adaptation (reformulate problem).

The user then designs his own concept solution of the new problem, for example, the user decides to use the same Inventive Principle (3-Local quality) from the old similar case in meaning and modify the old concept solution *Make each part of an object function in conditions most suitable for its operation. Redesign the heating part which can be placed in the container to heat the food*. He is inspired by the old solution and adapt it to *A recycling bin with dual compartments of different functions: the compartment which is used to store normal waste uses plastic bags while the other compartment which is used to store glass waste does not use plastic bags.* In this way, the user is able to solve his problem within two steps, retrieval and adaptation.

5 Discussion and Conclusion

In this paper, we presented a summarization of the proposed methodology combing Case-based Reasoning with lexical and semantic similarity calculations to solve an inventive problem and illustrate it with a case study.

The proposed approach is more advanced than the classical use of the Contradiction Matrix in three ways. Firstly, the time consumption in problem-solving process is expected to be reduced. The proposed approach escapes the use of the Contradiction Matrix by two steps: retrieval and adaptation. Secondly, it lowers the entry barrier of TRIZ for the new users. The proposed approach avoids the mapping between Evaluation Parameters and the GEPs which is manually implemented with the classical approach. Therefore, the new user will not have to identify their specific problems to the generalized engineering parameters. Because this is where the misinterpretation of the GEPs often occur and keeping the new users from a long-time practitioner [3]. Finally, our approach provide a tool to systematically collect and reuse the old experience coming from experts. In this way, the related information of old cases that are similar to a new problem can be exploited entirely by retrieval. The users are brought in front of the solutions and they can reuse or adapt them based on their needs. Once a new problem is solved, a new case is generated to enrich the case base.

However, there are still two problems to be solved. One is that the efficiency and robustness of our approach is still limited to a small number of case base. As future work, we will enrich our case base with more validated cases and test its performance with real industrial case studies in order to evaluate the quality of the cases.

Another is that we should include more tools that TRIZ provides in the future work. For example, the use of the 76 Inventive Standards and the scientific effects in order to have creative solutions from different domains.

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A Critical Comparison of Two Creativity Methods for Fostering Participatory Innovation: Implications to Improve TRIZ

Anna-Maija Nisula and Aino Kianto

1 Introduction

In today's business environment, companies compete to survive and succeed in a relentless quest for continuous innovation. An increasing number of innovations result from intense collaboration and the integration of the knowledge and perspectives of diverse actors (e.g. [1–3]), in which the contributions and participation of all actors are vital. Thus, companies desire input from diverse actors, such as employees, customers, users and other external stakeholders, to increase their innovation pace. Scholars have used terms like co-innovation [4], employee-driven innovation [5, 6], high-involvement innovation [7–9], user-driven innovation [10, 11] and participatory innovation [12] to emphasise the idea that novel ideas and innovations result from intense collaborations among diverse actors [2, 13, 14]. However, there exists less knowledge on how the participation of such diverse actors in innovation can be enabled, motivated and supported.

Creativity is the key driver of innovation [15–17]. Therefore, a variety of creativity-stimulating methods are widely used in innovation management. One of the most well-known methods is the theory of inventive problem solving (TRIZ) [18]. TRIZ represents a systematic way of thinking [19] and a methodology to foster creativity for innovation and inventive problem solving, especially in technology inventions. TRIZ relies on the assumption that technology development and invention are predictable and governed by certain laws [19, 20].

However, TRIZ tends not to explicitly consider the stimulation of participation: that is, the empowerment and acknowledgement of diverse actors' creative contributions to innovation development. This is problematic, as scholars suggest that a

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sufficient environment and climate for idea generation enhances employees' participation in innovation [6]. Moreover, the invention and development of radically new products and services—something that does not exist—often involves complex, fuzzy, non-linear and unpredictable processes (e.g. [2, 13, 21]). These findings, together with research showing that multiple aspects of innovation often require intense and fluent communication and collaboration among different actors (e.g. [2, 22]), may challenge such systematic approaches to innovation as TRIZ.

In line with a study by Ilevbare et al. [19], we suggest that participation-supporting creativity methods could be of use and value to TRIZ for a number of reasons. First, in a highly competitive business environment, accelerating innovation is essential, and companies need faster methods to produce innovations. TRIZ, as a relatively rigid method [19], may not support the innovative speed necessary in such invention processes. Second, the complexity of TRIZ means that practitioners must have a deep understanding of and experience with the method before they can achieve effective results [23]. Thus, beginners cannot use TRIZ fluently until they have learned it. In terms of participative innovation, therefore, the use of TRIZ may decrease possibilities to contribute among those who are unfamiliar with TRIZ. Third, innovative teams are increasingly multi-expert (i.e. composed of people from different fields of expertise) and temporary: groups of people gathered together to collaborate on a particular problem. As TRIZ is highly technology-oriented and requires learning, it may be difficult for non-tech members and temporary members to adopt.

To increase our understanding of the facilitation of participatory innovation, we compare two methods for fostering creativity: the lateral thinking method [24] and the improvisational theatre method. While the lateral thinking method is a cognition-based and structured approach to idea generation, improvisational theatre is an art-based method that emphasises the emergent nature of collective creation [25]. Critically comparing these two methods is a fruitful approach to increase our understanding of the role of creativity and ways to support it in participatory innovation. The comparison also increases our understanding of the suitability and limitations of the two methods for fostering participatory innovation in organisations. Thus, by comparing these two methods, we shed light on the enablers of participatory innovation and discuss the advantages of each method for fostering creativity and innovation. Thereafter, we discuss implications for participative innovation and the systematic TRIZ method. Specifically, we suggest the two studied methods can serve and complement the identified weaknesses of the technology-oriented TRIZ method (see [19]).

2 Theoretical Background

2.1 Participatory Innovation

Participatory innovation [12], or high-involvement innovation [7, 8, 26], refers to the realisation of the potential of organisational employees and various other stakeholders to generate and implement novel ideas to achieve improvements, develop new products and processes and organise work and changes. In product development involving designers/producers and users, participative innovation is often described as participatory innovation [12], which term we use also in the present study. Participative innovation is rooted in an overall ability to enable, motivate and support a wide set of actors to contribute to the development and application of new ideas, improvements and innovations [7, 8, 26].

Participatory innovation is a joint activity through which solutions emerge through the constructive integration of differences and perspectives. A fundamental characteristic of participative innovation is the full empowerment of various stakeholders in co-creation and innovation activities throughout the entire innovation process, whether this involves sourcing data on user needs or collecting insights from front-line employees. This kind of functioning refers to the behavioural patterns, practices and cultures in an innovation group or environment that focus conscious attention on empowering participants in innovation and developmental processes to ensure that ideation, problem finding and problem solving are activities that belong to all participants.

The stimulation of the creative potential and participation of individuals and groups should consider several aspects. Firstly, it should facilitate the creative contributions of participating individuals, that is, generation, voicing, development and realisation of ideas. Second, it should build suitable conditions for creative interactions among people to enable the emergence of group power, since creative contributions (i.e. idea generation, development and realisation) occur through social interactions among participating members. More specifically, the voiced ideas of others often trigger associations and build novel connections in individuals' thoughts [27–29], and enable individuals to build on others' ideas, thereby increasing participation. In addition, the creative process is unpredictable and subject to unexpected turning points, which can also increase participation (i.e. contributions from stakeholders).

2.2 Comparing the Improvisational Theatre–Based and Lateral Thinking Methods

The improvisational theatre-based method is an art-based method that emphasises the emergent nature of collective creation [25, 30, 31]. More specifically, an improvised theatre emphasises participation and the collective process of co-creation as they play out in mutual and intense interactions among participating members [32–36].

The lateral thinking method [24, 37] aims to increase participants' potential to identify ideas outside normal thinking patterns through a structured approach in which divergent and convergent thinking are promoted in an iterative fashion. As an idea generation method, it supports the creative thinking component [38] of creativity.

In the following, we contrast these two methods in terms of their points of view on creativity and their backgrounds, goals, processes, principles and possibilities with respect to participate the people involved in the innovation process. Table 1 compares the key characteristics of the two methods.

2.2.1 Creativity

Improvisational theatre follows an art-based approach to creativity. In improvisational theatre, creativity is understood as a process that integrates people's ideas, contributions, imagination, interactions and collective meaning creation, as well as

Table 1 Comparison of lateral thinking and improvisational theatre methods

	Lateral thinking [24]	Improvisational theatre based method
Creativity	Serious, deliberate and systematic	Freeing imagination, i.e. combination of imagination, improvisation, intuition, emotions, passion, motivation
Background	Individual cognitive creative thinking	Art-based method. Holistic and social systemic view including both individual and collective creativity
Goal of the method	Improving the width and depth of thinking	Developing creativity, imagination and improvisational abilities (individual and collective)
Process	Structured (step-by-step) process	Non-structured Enables event and case driven development path (tailor-made)
Objective of the process	Defined or given in a question form	Not clearly defined problem (openness)
Interaction	Acknowledges both individual and group working	Acknowledges both pair and group working
Climate for creativity	Not supported	Strong efforts in building climate for creativity
Group cohesion	Not supported	Strong efforts in building group cohesion
Individual skills	Broadening thinking skills	Triggers to recognize limiting thought patters, mental models and behaviours
Key principles	Extending thinking by asking questions are there other ways to carry out the same idea, are there ways to accomplish the same objective	Building on others ideas ('yes, and...') Utilizing whatever (emotions, imagination, environment, intuition) as material for performance Shared responsibility and leadership
Utilization	Effective tool to collect ideas from particular theme of problem. Can be used also individually in daily life.	Improving both individual and collective creativity Organizational development Fostering organizational creativity Can be adopted as a personal behaviour

such factors as environmental influences, timing, fortune and mistakes. Rather than seeing creativity as a linear process, improvisational theatre views creativity as distributed [25] or as a rhizome, such that horizontally dispersed knowledge can be connected to any node [17, 39]. Thus, creativity is rooted in connections and collective activity [40, 41]. In addition, improvisational theatre also highly emphasises individuals' ability to imagine, utilise their interpersonal creativity and contribute to the collective processes of creation.

The lateral thinking method describes creativity as serious, deliberate and systematic, rather than artistic, natural talent or 'acting crazy' [24, 37]. De Bono [24] and Provost and Sproul [37] highlight the difference between artistic (natural talent) creativity and serious creativity in the lateral thinking method. In the lateral thinking approach, individuals are seen as key sources of ideas. Similarly, West and Richter [42] understand individual creativity as idea generation: that is, a process involving an individual's creative characteristics (compared to innovation, which involves the implementation of these ideas in practice). However, in lateral thinking, creativity is seen as a fundamental basis for improving activities in organisations, for supporting problem solving and innovations and for securing full use of existing knowledge. More specifically, the lateral thinking method fosters the creative thinking component [38] of creativity.

2.2.2 Goal

The improvisational theatre-based method aims to develop both individual and group interactions and to empower participants through collective creation. It uses several different kinds of exercises or techniques to foster joint idea generation. In improvisational training, rational goals are seldom used during the initiative steps of the training. Thus, the outcomes of improvisational workshops are seldom concrete numbers of ideas; rather, such workshops yield intangible outcomes, such as improved communication, interaction, group cohesion, climate for creativity and freedom to imagine and contribute to collective creation, but also collectively generated idea.

By contrast, the lateral thinking approach is goal- and outcome-oriented and designed to be applied to particular and well-defined themes or problems. Its results include the production of a number of ideas and concepts around a given problem. At best, a session designed to address a specific problem will produce one or a few potential solutions for further development and testing and to serve as the basis for decision making.

2.2.3 Process

The improvisational theatre-based method provides flexibility in fostering creativity. Although it utilises a ready-made set of exercises, it is always tailor-made for each case and the primary purpose of the training. Planning an improvisational theatre-based session begins with identifying the participants. Training sessions usually start

Fig. 1 Lateral thinking process

with a 'warm-up' period. If the participants involved do not know one another, training may also include 'getting to know one another' and 'ice-breaker' activities. In general, the purpose of improvisational theatre-based training is to define what constitutes a process. For example, if the aim is to foster communication and interaction within the work community, more weight is placed on exercises supporting these aims. Building team cohesion may form another combination of exercises. In addition, the content is influenced by participants' expertise. In other words, there is a difference between a process designed for beginners and one designed for more advanced improvisers. Indeed, improvisational theatre fruitfully models social interactions in which meaning emerges from intentions, actions and responses [30].

The lateral thinking method follows a systematic process (Fig. 1) that begins with a problem definition or a given problem (the objective of idea generation) and continues with a divergent thinking phase. Individual idea generation initiates the process, and this is followed by a conceptualisation of ideas either in pairs or in groups. During this process, it is possible to add new ideas. Individual ideation is used to avoid social loafing, in which only a few people contribute while others remain passive spectators. In addition, distractions to individual ideation (e.g. social influences by others) should be avoided. Others' ideas are seen not as welcomed triggers, but as cueing and limiting disturbances to individual ideation. Furthermore, working individually is utilised to avoid social inhibitions (e.g. feeling uncomfortable in groups) [37]. During the subsequent convergent thinking phase and throughout the evaluation, selection and development of ideas, one or a few possible solutions are selected for testing. The convergent thinking phase can be carried out as group work or can be done by the problem owner. Throughout the process, variations may be caused by the choice of different kinds of supporting tools, such as provocations, random entries or challenges, which can be introduced during different stages of the process as needed. The advantage of the lateral thinking method is its ability to survey a diversity of individual experiences and opinions.

2.2.4 Interaction

Improvisational theatre emphasises the social relations and interactions among participating members throughout the workshop. Indeed, all exercises are carried out in pairs or in groups, during which participants focus on listening, awareness and communication (including non-verbal communication). By breaking conventional social behaviours and offering a new set of rules for social interaction, improvisational trainings enable participants to discover and recognise their limiting thought patterns, mental models and behaviours.

By contrast, the lateral thinking method does not pay any attention to interaction, social relations or trust-building among participating members, although it alternates between individual and group work. An individual who struggles to produce ideas during individual idea generation phases due to strong internal criticisms or a lack of familiarity with idea production may find the lateral thinking method frustrating. However, some individuals prefer to generate ideas alone, and they may appreciate the opportunity for individual idea generation. Next, during the group work phase, participants work together to organise ideas under concepts and to generate ideas that build on what has already been presented. Furthermore, idea extraction and evaluation can be conducted as group work.

2.2.5 Climate for Creativity

Building a climate for creativity is fundamental for improvisational theatre. By building trust and stimulating team cohesion, mutual support and a sense of shared leadership and responsibility, improvisational theatre, at best, invites participants to contribute openly. By contrast, the lateral thinking method does not focus on building a climate for creativity and participation.

3 Methodology

This study adapts a qualitative research approach to investigate the applicability of two distinct creativity methods for fostering participatory innovation. Qualitative research typically answers 'how' questions [43, 44]. More specifically, to examine how lateral thinking and the improvisational theatre-based method can be used to further participative innovation, we execute innovation workshops with both methods. In addition, we use comparison as an approach to reveal the similarities and differences between the two methods.

We collected data from two creativity workshops carried out among the personnel of a research unit. Each workshop lasted approximately 2.5 h. We interviewed the participants after each exhibit, conducting eight participant interviews in the lateral thinking workshop and seven participant interviews in the improvisational theatre workshop. Each interview lasted approximately 13–35 min. In addition, we used the recorded reflection discussions and group work sessions as supplementary research data.

The interview data were transcribed and analysed using content analysis. We were interested in the participants' perceptions and experiences of the two workshops. During the interviews, we asked about how the participants experienced the workshops, how each method fostered creativity, whether the participants experienced any difficulties during the workshops, what the participants learned, what the key outcome of the workshops was and where the participants would use the workshopped method in the future.

The first author of this paper acted as a facilitator in both workshops, and the second author took part in the demonstrations as a participant.

Workshop 1: Improvisational Theatre

The improvisational theatre-based workshop was based on improvisational theatre exercises that are widely known and used in improviser communities [32, 36] and improvisational training courses in which the responsible author has participated. Appendix I presents the events in the improvisational theatre workshop. This workshop included basic exercises, starting with warm-up trainings and followed by trainings concentrating on the key principle of improvisational theatre: agree, accept and add (known also as 'yes, and...'). More specifically, these exercises focused on the fundamental improvisational principle of building on others' ideas. Telling a common story one word at time is an exercise that illustrates the distributed creativity, real-time action and spontaneity of such activities. The core nature of improvisational theatre is that creation happens through real-time interactions between participants and their context and that emergence is impossible for a single participant to control.

Workshop 2: Lateral Thinking

The lateral thinking-based workshop began with the definition of a problem (i.e. the objective for the session; Table 2). The problem was described in the form of a question: 'How could we develop our future living?' The idea generation phase began with individual ideation, during which each participant contributed individual ideas on Post-It notes. The extraction phase involved a conscious and systematic organisation of ideas and concepts. The lateral thinking process uses a variety of additional tools, such as individual ideation triggered by random entry or provocation. In random entry, an individual blindly points to a random word from a list of

Table 2 Events in the lateral thinking workshop

	Lateral thinking process	Content	Type	Tools
1.	Defining objective or modifying given objective	Objective in question form *"How could we improve..."*	Group	
2.	Idea generation/ideation	Individually producing ideas and putting ideas into post-its	Individual	Provocation, random entry
3.	Concept behind each idea	Ways to ...	Group	
4.	Extending concepts	Are there other ways to ...	Individual/ group	
5.	Concept extraction		Groups or case owner	
6.	Selecting solution		Groups or case owner	Six hats

words and uses it to trigger ideation. In provocation, negative and reverse wording are used to force a shift away from familiar thinking patterns. The six hat tool is an approach to parallel group thinking in which, for example, a selected solution is evaluated through different perspectives (colours or hats; [24]), such as, from the perspective of objective data, by asking why the solution may work and why the solution may not work, possibilities as well as by identifying feelings. In this demonstration workshop, we did not continue the process until the end, when the few most promising ideas would usually be prioritised and selected for further development or testing.

4 Findings

In the following, we discuss the key findings concerning the similarities and differences in participants' impressions about the two different methods for facilitating participative innovation.

4.1 Improvisational Theatre–Based Creativity Stimulation

The improvisational theatre-based workshop comprised several small exercises. It started with warm-up and ice-breaker exercises that involved the whole group. During the warm-up exercises, we accepted and celebrated failures, which the participants considered a lot of fun and very enjoyable. After each exercise, we briefly reflected on the feelings and experiences of both the participants and the facilitator. As facilitator, I also shared the key idea of each exercise. From the very beginning of the workshop, the participants were laughing and smiling, and it seemed that they enjoyed the exercises. After the warm-up, we engaged in the basics of improvisation: namely, exercises involving 'agree–disagree' and 'agree, accept and add'. These were carried out in pairs, while the 'yes, but...' exercises were carried out in groups of five or six people. The word-by-word story telling was challenging. Following a reflective discussion, during which mistakes and problems were collectively shared and discussed, the participants expressed a desire to tell another story by carefully listening to others. During the final discussion, the participants felt very positive and inspired. However, few expressed missing concrete results, such as a number of generated ideas or other useful outcomes.

4.1.1 Participants' Experiences

Without exception, the participants experienced the workshop as fun and playful. All expressed having positive feelings during and after the exercises.

4.1.2 Supporting Creativity

The respondents felt relaxed and able to throw into experiencing and discuss their experiences. One respondent considered the workshop effective in helping them get to know one another:

In 2 h, you learn more about others—in telling a common story or in making offers for others [agree-disagree]—than in working 2 months in the same working place. I feel that it tells 'between the lines' how people think and act and even such things that one does not necessarily have thought—however, it becomes conveyed.

You get to know people, and the setting is so informal. There is no formality like in the meeting room, and you learn whole new things about people.

The participants also found that the experience created common understanding and team cohesion, as the following quote describes:

It can be used to test what this group could be capable of when working together. Perhaps it's not so much producing something new. It's more like reinforcing the group; bringing the individuals together.

4.1.3 Learning

The participants learned about themselves and found that they were capable of spontaneous contributions. As one participant noted: '... but I noticed that I am able to express something spontaneously...' The participants also learned to see group work in a new light. As one participant described:

It also taught me to work in a group, because whenever I'm in a group situation, when everyone else is quiet, I feel like I have to do something. Now I had to listen—and just noticing how little you can influence the story when everyone has to contribute one by one, and noticing that you can't dictate how the story goes—it makes you remember that you're always only a little part of the group.

4.1.4 The Key Outcomes of the Method

The key outcomes of the improvisational theatre workshop included freeing and encouraging individuals to experience, throw themselves into situations and contribute, as the following quotes describe:

Practicing it could make it easier to get more involved, forget about any inhibitions and just let go!

And when you get into a creative mood, a playful state, it absolutely frees you, because they break old routines and the tacit front end of innovation. It could work really well as a warm-up exercise before systematic idea generation.

The participants also felt that the improvisational training models stimulated social interaction and collective creation. As one participant described:

It's useful for the kind of social interaction that is essential in innovation and all work. It nicely incorporates joint idea generation and the social aspect of creativity.

The participants noticed that, through practice, they could achieve much more in social interaction.

4.2 Lateral Thinking Method–Based Stimulation of Participative Innovation

The lateral thinking exhibit began with the participants choosing a target topic from two alternatives. We discussed and modified both topics to be suitable for the exhibit and collectively elected the choice 'How could we advance more sustainable building and city living?' The process began with individual idea generation, during which each participant individually generated ideas by putting them on the Post-Its (one idea per Post-It). After a few minutes, I, as a facilitator, introduced random entry and provocation tools to trigger further idea generation. We continued the individual idea generation for a few minutes. Thereafter, the participants were grouped into pairs and started to build idea concepts from their Post-Its (i.e. they grouped similar kinds of ideas under similar concepts). They also added new emerging ideas or concepts. Following this pair group work, the idea concepts were put on the wall. We all began to look at the ideas and to see what the other groups had produced. Though the ideas mostly dealt with the same phenomenon, one pair was surprised about one of the developed idea groups, which they had not considered. The concepts were then grouped again (i.e. similar kinds of concepts were connected), and new ones were created. Next, the ideas and idea groupings were be re-worked in order to reduce concepts and select possible solutions for further development. During the short discussion after the session, the participants expressed missing real collective idea generation, in which someone else's ideas can trigger one's own idea generation.

4.2.1 Participants' Experiences

The lateral thinking method was considered familiar and even traditional, given its similarities to several other methods for collecting and generating ideas both individually and in groups. The respondents experienced the process as individual-driven and felt that that it did not utilise the power of the group from the early steps of the process. This consensus is described in the following two quotes:

The fact that people were in the same room was not really taken advantage of. I feel that we would have got the same number of ideas if we had been alone in our offices and written down our ideas.

It was all based on what we had written down by ourselves. I had the feeling that nothing special had happened.

4.2.2 Supporting Creativity

The respondents found that the lateral thinking method was not creative. As one participant explained:

Perhaps it's the fooling around that has associations with creativity! I just had a bit higher expectations.

Some of the participants experienced the individual idea generation phase as difficult. For example:

The topic was wrong for me personally. I couldn't come up with ideas. It felt difficult, and I realised that they weren't all that original. I saw that others came up with some good ideas, but the topic just felt alien to me.

Others were more familiar with individual ideation:

At first, it felt great working alone, but then the ideas just ended, and when we started working with a partner, the ideas started coming again, and the tools [random word entry and provocation] even increased it. It may not be suitable for everyone, but for me, it's perfect.

The use of tools, including random word entry and provocation, was seen as triggering creativity.

4.2.3 The Key Outcomes of the Method

The lateral thinking method was considered suitable and effective for surveying and collecting ideas using simple techniques in a short time. However, the participants did not see this process as having the potential to support the creation of radical and totally new openings.

5 Discussion

In this chapter, we discuss the findings from the point of view of participative innovation. Participative innovation demands the empowerment of diverse actors in the generation of novel outcomes. Thus, the critical question is: How can we best empower and stimulate such wide participation in innovation activities?

The two methods studied in the present study differ in their potential to encourage and empower the full participation of the people involved. The improvisational theatre-based method encourages participants to engage in spontaneous contributions by accepting failures and building on others' ideas. As a form of emergent joint creation, it fosters playfulness, engagement and full participation throughout the creation process. By contrast, the lateral thinking approach shifts between individual and group work, taking advantage of the wide diversity of individual ideas and experiences. This method is also, by nature, an idea generation method, as it aims to increase the number of generated ideas; therefore, it does not focus on ensuring full participation throughout the co-creation process.

Concerning the role of creativity in fostering participatory innovation, we explored how idea generation, development and realisation in practice are supported and facilitated. In improvisational theatre, creativity is understood as a holistic and collective social activity and as being essentially embedded throughout the innovation process. In this respect, improvised theatre better responds to the purposes of participatory innovation because it builds suitable conditions (i.e. climate and social connectivity) for people to contribute and engage in innovation. Simultaneously, it develops the participating members' abilities to contribute to the collective creative process. By contrast, in the lateral thinking method, creativity is conceptualised as idea generation [24, 37, 42]. Specifically, this approach provides a tool to extend thinking (divergent thinking) and, thereafter, to compose ideas (convergent thinking). This method is useful during the front end of innovation and, in particular, for problem solving situations; however, it does not foster participation throughout the innovation process. As a result, participatory development and the implementation (realisation) of ideas in practice may suffer.

The primary obstacle to creativity is individuals themselves. If individuals consider themselves 'not creative', it may prevent their contributions to situations that require creativity and activities outside of their comfort zones. For participatory innovation to occur, it is fundamental for the people involved to use their potential and contribute to the innovation process. In this respect, the methods that aim to increase participants' creativity can increase the likelihood that they will engage in innovation. More specifically, individuals' beliefs that they can perform creative actions evolve through positive experiences. Creativity training can provide such positive experiences and, thus, serve as a starting point for increased participation. In general, people will opt to perform tasks in which their competency beliefs are high and to avoid tasks in which they anticipate their performance skills to be low [45]. These tendencies can be addressed and rewired through training. By offering participants experiences of being creative, either through generating and selecting ideas (lateral thinking) or engaging in playful co-creation (improvisational theatre). Thus, both of the methods examined in this research have the potential to increase participants' likelihood of engaging in future creative behaviours.

Furthermore, as both individual attributes and contextual factors influence participative innovation, facilitation methods should capture both of these levels simultaneously. The improvisational theatre method focuses on building sufficient circumstances and climates for creative interactions to enable the emergence of group power. It is rooted in collective improvisation, in which co-creation happens through social interactions among participating members. By contrast, in the lateral thinking method, conditions for interaction are built through the iterative use of both individual and group work.

Concerning the nature of the innovation process, the studied methods take nearly opposite views. The improvisational theatre-based process is a non-linear innovation process rooted in the rhizome nature of knowledge. In this approach, any idea or contribution can be connected to any previous idea or contribution, and the process outcome is somewhat open-ended. This enables individuals to build on others' ideas and develop single ideas further. Therefore, the improvisational theatre-based approach provides more flexibility and allows for the occurrence of radical turning points. By contrast, the lateral thinking method is a structured and step-by-step process that yields a huge number of ideas and some potential solutions as outcomes.

Drawing from these two examined methods, we suggest that the improvisational theatre-based method develops participants' capabilities to interact, openly share their ideas and experiences and build on the ideas of others, thereby promoting connectivity, continuous exchange and dialogue among participating members. Improvisational theatre is also a powerful method of empowering and committing participants that can increase participation in innovation. By contrast, the lateral thinking method is a viable method to use in particular problem situations and at the beginning of the participatory innovation process, when it is necessary to collect a broad array of ideas. However, this method does not focus on committing members to participating in idea development and implementation in practice.

6 Conclusions

In this paper, we investigated two approaches to fostering creativity in participatory innovation. These two methods, which represent different backgrounds, views of creativity and goals and processes, offer different possibilities to facilitate participatory innovation. While the improvisational theatre-based method is powerful for building a conducive climate and strong social, communicative and creative interactions among participants, the lateral thinking method is effective for surveying and organising ideas within a particular problem field.

Our study increases our understanding of the applicability of the creativity-stimulating improvisational theatre-based and lateral thinking methods for fostering participatory innovation. In so doing, it sheds light on the critical enablers of participatory innovation. Our findings contribute to earlier research (e.g. [2, 12]) by suggesting that, when attempting to stimulate actors' participation in the generation of novel outcomes, it is necessary to examine the social dimension and the collective and emergent nature of co-creation in participatory innovation. This finding is particularly important in relation to systematic and structured processes of innovation, like TRIZ [20].

Our study contributes to the identified weaknesses of the TRIZ method (e.g. [19]) by suggesting that while aiming to increase speed in innovation, the innovation managers should understand innovation process as flexible and use facilitation or creativity methods that enable desired speed in innovation. In addition, the method should be easy to implement with beginners or temporary participants. To accomplish these goals, the TRIZ procedure could incorporate more participative elements in order to increase possibilities for customers or other members who may be unfamiliar with the method to contribute. Innovation results from intense collaboration and the integration of the knowledge and perspectives of diverse actors (e.g. [1–3]), who are not always technology-oriented. Thus, the technology-oriented

TRIZ method may need to be adapted to include practices that support the integration of diverse perspectives.

The managerial contribution of the paper highlights the strengths and weaknesses of each method in terms of participatory innovation by showing how the spectrum of available methods enables practitioners to develop more tailored and case-sensitive methods for facilitating participatory innovation. Indeed, to stimulate the development of participative innovation, practitioners require a set of methods that empower the creative potential of diverse participants by building a climate and energy suitable for joint creative processes.

Our research involved several limitations that should be addressed by future studies. Firstly, our study involved only one exhibit each for the two creativity methods. As our goal was to investigate the potential of these two creativity methods to stimulate the participation of diverse actors in innovation, we believe that our comparison represents a good first step in shedding light on the methods' ability to boost participation. However, future studies should explore these methods via multiple cases and with different types of participants. In addition, future studies should explore a wider set of creativity-supporting methods, including creativity tools from the TRIZ toolset.

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Problem Formulation of Screw Feeding System of Fibrous Materials Using TRIZ

Marek Mysior, Sebastian Koziołek, and Eugeniusz Rusiński

1 Introduction

Torrefaction is a thermal pretreatment method under atmospheric pressure where the biomass (processed material) is heated to temperatures above 200 °C in oxygen reduced atmosphere [1]. There is a growing interest in application of this pretreatment to new materials that results in the carbonized solid fuel resembling closely coal quality. There are two types of biomass being processed nowadays: lignocellulose biomass waste (f. ex. agricultural, wood, biodegradable industrial waste, etc.), and non lignocellulose biomass waste (f. ex. municipal solid waste, industrial waste, RDF (Refuse Derived Fuel)) [2]. The torrefaction of lignocellulosic biomass is a well-known process described by many researchers [3, 4], but there is a limited amount of information related to processing of non lignocellulose biomass waste, which is currently of the growing interest in the waste processing industry [5, 6]. This problem is related to the limited knowledge in design of machines dedicated to process this type of biomass as well as the process parameters, especially regarding the behavior of the material at each stage of the process of its torrefaction. One of the possible solution to this problem is to adopt existing solutions, in particular continuous auger reactors [7, 8] to process non-lignocellulosic biomass. Screw conveyor is a well-known and widely applied solution to transport or elevate various materials in many industries like food industry, metalworking processes, plastic and others and the number of application is still growing. In waste processing, screw feeders are being used to transport material through the process installation and to supply the reactor in material for treatment directly from the hopper [7]. There is a wide knowledge on how to design screw feeders [9, 10] and even auger reactors

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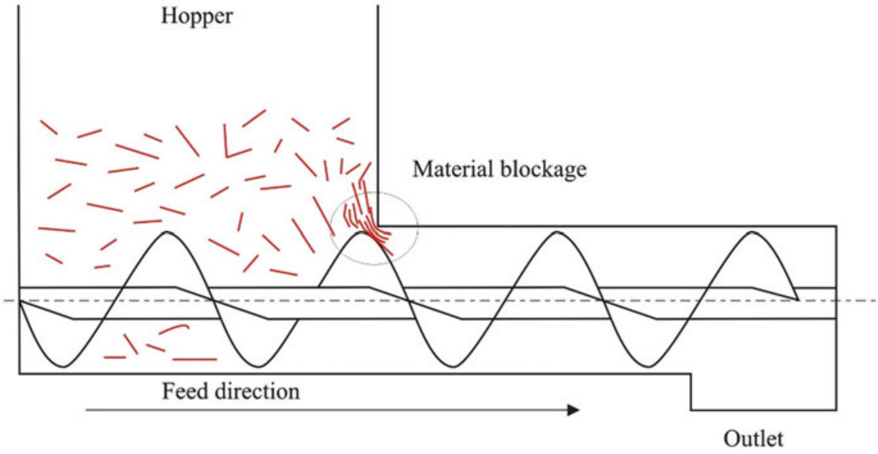

Fig. 1 Blockage of the flaky bulk material (RDF) during discharge in the screw feeder

[7, 11, 12], but it does not take into account the morphology and shape of the material being processed. For this reason, currently known process of design of screw feeders and auger reactors cannot be applied directly to such materials being processed nowadays like municipal waste or RDF, because the material being processed exhibits different properties that influence its movement and torrefaction process itself, resulting in process blockages and other difficulties that may occur during torrefaction process of non-lignocellulosic biomass. The schematic representation of the material blockage in the screw feeding system is shown on Fig. 1.

2 Problem Description

Application of the screw feeder dedicated to the torrefaction of lignocellulose biomass exhibits very good properties in terms of effectiveness of transport and sealing properties [3, 13]. Applying this solution to non-lignocellulosic biomass however may be connected with series of limitations connected with the shape of particles of such materials like RDF or municipal solid waste. The flaky structure of this material is known to be very difficult in handling using any form of conveyors [14, 15]. The description of the blockage of the material in screw feeder was performed using system operator (Table 1).

The problem of material blockage in the feeding system is of huge impact, because it stops the torrefaction process, because no material is being delivered to the reactor. Moreover, the feeding screw is being stopped that may lead to destruction of electric motor due to its overheating.

Table 1 System operator for the bulk material blockage in the screw feeding system

	Past	Present	Future
Supersystem (Reactor)	Material being constantly supplied to the reactor	Decrease in material flow	Material flow stopped
System (Screw metering)	Material discharge from the hopper	Material blockage	Disengagement of the motor
Subsystem (Screw)	Rotation of the screw and material feeding	Rapid deceleration of the screw	No movement of the screw

3 Functional Modelling of the Torrefaction Process

In order to determine the factors that influence the operation of screw feeding system in the process of torrefaction of biomass regarding process blockages, the functional modelling of the process was performed using IDEF0 (Icam DEFinition for Function Modeling) to describe relations between each stage of the process, mechanisms and controls that determine the realized functions. Then, the hypotheses analysis was performed to extract relations and parameters describing the analyzed system. Finally, the contradictions were formed and set of potential solutions was defined. The functional modelling of lignocellulosic biomass processing was performed at two levels.

As it was shown on Fig. 2, the main function was defined as torrefaction that transforms the raw biomass (I1) into the carbonized solid fuel (O1) using heat (I2) in the conditions of oxygen-reduced atmosphere (C1) using dedicated process equipment (M1). The additional outcome of the realized function is the production of gas (O2) being the result of the torrefaction of biomass. The function being realized is

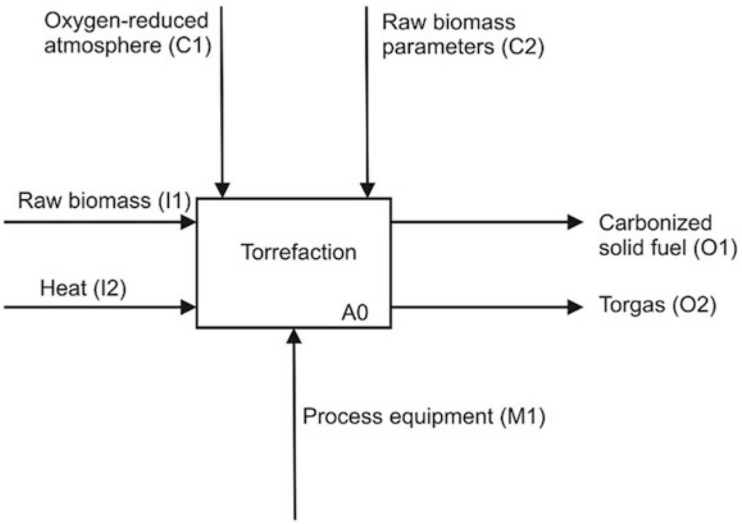

Fig. 2 IDEF0 function model of the torrefaction process- top level diagram

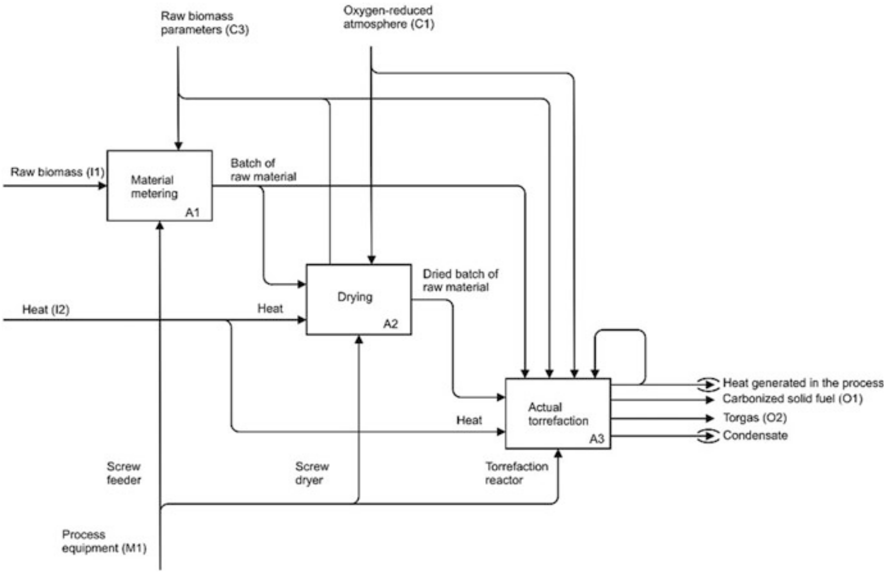

Fig. 3 IDEF0 function model of the torrefaction process- child diagram (A0)

also controlled by the raw biomass (C2), that determines the process parameters. Stepping further into IDEF0, torrefaction may be divided into three sub-functions: material metering (A1), drying (A2) and actual torrefaction (A3)., as shown on Fig. 3.

The material metering is being realized by means of screw feeding system is responsible for providing constant flow of biomass into the torrefaction reactor from the hopper and provides proper sealing conditions for the reduced oxygen temperature inside the reactor. The next stage is connected with preparation of the biomass batch to the torrefaction process by reducing the water content. Finally, the dried biomass batch is being subjected to actual torrefaction that results in carbonized solid fuel and torgas. The set of functions realized by the screw feed system is presented in Table 2.

Table 2 Functions realized by the screw feeding system

<screw feeding system>	<to deliver><materia> <to stop><oxygene>
	<makes><batch of the material> <makes><oxygene reduced atmosphere>

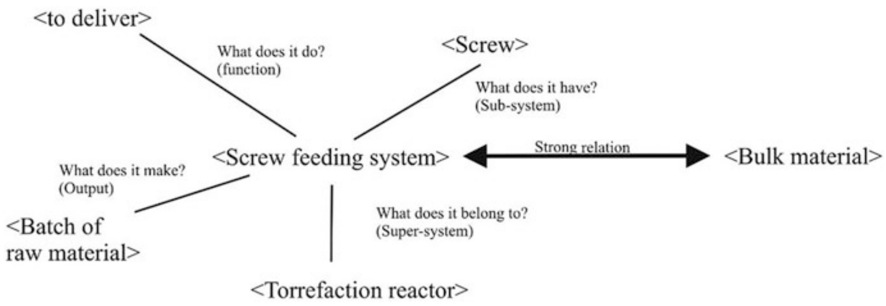

Fig. 4 Hypothesis analysis for the screw feeding system, description of the system

4 Problem Formulation

Using hypotheses analysis, it was possible to determine relations and parameters that are connected with screw feeding system. The analyzed system was defined as the <screw feeding system>, which is in a strong relationship with the <bulk material>. The super-system was said to be the entire <torrefaction reactor> and the subsystem to be the <screw>. The main function of the system was defined as <to deliver> and the main outcome as <batch of raw material>. The diagram presenting all the above features of the analysed system are presented on the Fig. 4.

After the description of the function of the system, its main outcome, super- and sub-system as well as the system being in strong relation with the screw feeding system, it was possible to define relations between each of the elements. Those relations are physical phenomena that can be further quantified in terms of parameters, among which the contradictions may be formed. Hypotheses analysis is presented on the Fig. 5.

Based on the relations showed on the Fig. 5, it was possible to determine the set of parameters that describe the behavior of the analyzed screw feeding system for each of the relations. Those parameters are presented in the Table 3.

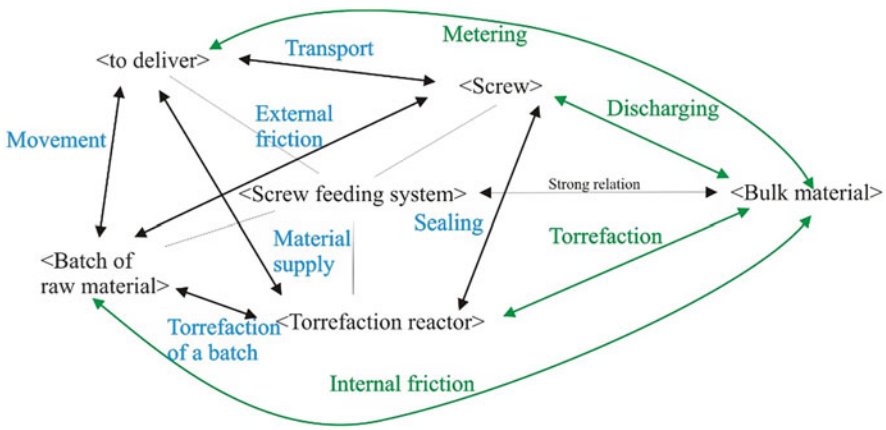

Fig. 5 Hypotheses analysis of the screw feeding system, relations between diagram elements

Table 3 Description of relations describing the screw feeder with their parameters

Relation	Parameters
Transport	Mass flowrate [kg/h] Volumetric efficiency [m^3/h] Power [W] Conveying force [N]
Sealing	Oxygen level in the reactor [%]
Torrefaction	Water content reduction [%] HCV of a product [J] LCV of a product [J]
Movement	Conveying force [N] Resistance area [mm^2]
Friction	Friction coefficient [-] Friction area [mm^2]
Discharging	Angle of repose [deg] Density [kg/m^3] Shear force [N] Normal force [N]

Comparing the process of material feeding of lignocellulosic and non-lignocellulosic biomass, the only difference is the bulk material used for torrefaction process. The difference in parameters is the density and internal friction area for both types of biomass. Bulk materials like RDF or municipal solid waste have flaky structure, in which two spatial dimensions of the particle are much bigger than the third one, resulting in significantly bigger internal friction area inside the bulk solid. Flaky materials move without any blockages when they are not compressed, but any normal force applied to this material leads to immediate increase of the conveying force [16]. Based on this, the following contradiction was formed (Fig. 6).

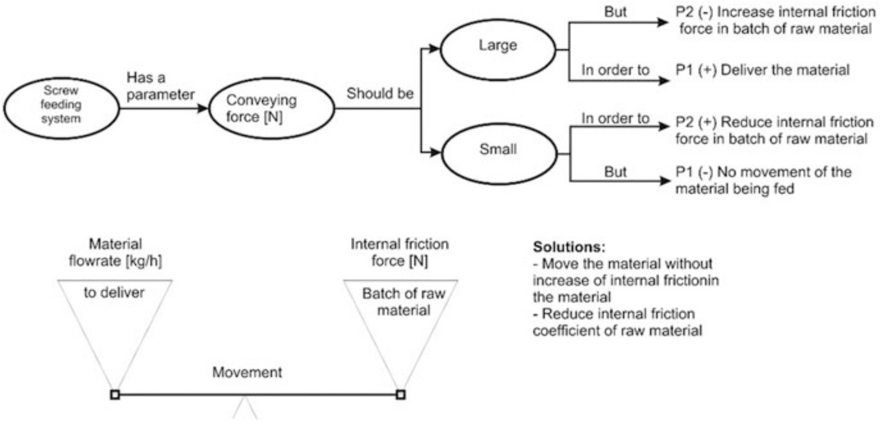

Fig. 6 Results of the contradiction analysis for the screw feeding system

When the blockage of the materials occurs, the conveying force increases rapidly, increasing resistance of the bulk material to further movement by means of increased shear resistance.

5 Conclusions

Application of screw feeders to torrefaction proces of non-lignocelulosic biomass may be connected with handling problems related to material movement blockages especially in the areas of potentially high shear force. Using system operator to describe the problem made it possible to assess the severity of the problem for the entire torrefaction plant. It was shown, that the process blockage at the discharging hopper of the screw feeding system leads to stop of the screw rotation and potential damage to the screw motors. Proposed problem solving approach was based on the functional analysis using IDEF0 to define the function of the system to be analyzed in the context of the entire torrefaction process. Application of the hypotheses analysis allowed to list relations and parameters that are directly connected with the bulk material metering system in the screw feeder. The main difference between non- and lignocellulosic biomass in the context of defined parameters is in their density and internal friction area, that are both much smaller and much bigger for the materials like municipal waste or RDF. Large friction area may lead to large values of shear force in the material as a result of high normal stresses, that occur at the time of conveying of the material. The possible solution to this problem may be to reduce the internal friction of the bulk solid by pre-compaction of the material into granular or pellet form or to minimize the amount of normal stress to the flakes by applying multidirectional conveying force.

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Quantifying and Leading Innovation with TRIZ Within Competitiveness Strategies

Stelian Brad and Emilia Brad

1 Introduction

Competitiveness, innovation and productivity are separate, but interrelated issues, which must be concurrently tackled by any economic entity (e.g. companies, economic clusters, regions or nations) in order to ensure sustainable economic growth and social welfare [1]. In order to align various kind of resources towards higher levels of prosperity, strategies of economic competitiveness are formulated. There are various approaches to support the construction of such strategies. In this framework, the most prominent tool for analyzing the competitive advantage of organizations or larger ecosystems is the so called "Porter's diamond" [2]. The model, in its basic form, considers four determinants (attributes) that create the environment in which "companies are born and learn how to compete" [3]. They are: (1) factor conditions; (2) demand conditions; (3) related and supporting industries; (4) firm strategy, structure and rivalry. Each of these attributes is dependent on the others, thus all together forming a self-reinforcing eco-system [3]. Porter's diamond model has gained in popularity, being largely adopted to analyze various cases of competitiveness-related problems, from small firms to clusters, industrial sectors and nations. For example, studies on cluster's competitiveness with this model are done in many works such as [4–9].

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Despite the presence of many researches done to improve the application of the famous Porter's diamond model, none of them provides solutions on how to approach the connections between the model's determinants. In other words, the multiple links between factor conditions, demand conditions, related and supporting industries, firm strategy, structure and rivalry, are not operationalized in none of the current research works.

Thus, the objective of this paper is to introduce an approach that systematically builds-up the Porter's diamond, including the links between its attributes. The article is organized as follows. Section 2 is dedicated for the theoretical description of the approach. It explodes the links between the model's blocks into relationship matrices. The components of the Porter's diamond blocks are structured as SWOT elements and are analyzed in terms of correlations to identify innovation challenges. TRIZ tools are used to tackle barriers and conflicts between the elements within the model. The theoretical framework is exemplified in Sect. 3, where the case of an IT cluster is investigated. The case study reveals the effectiveness of the proposed methodology. The supplementary effort required to detail the Porter's diamond model pays for the quality of the information obtained. The paper ends with conclusions and ideas for further researches in this area.

2 Methodological Toolbox

The graphical form of the classical Porter's diamond model is shown in Fig. 1. It highlights the six links that exist between the four blocks of the model. A major focus of this paper is on these links, whose relevance was not yet treated in the previous researches from the literature in the field. The methodology proposed in this

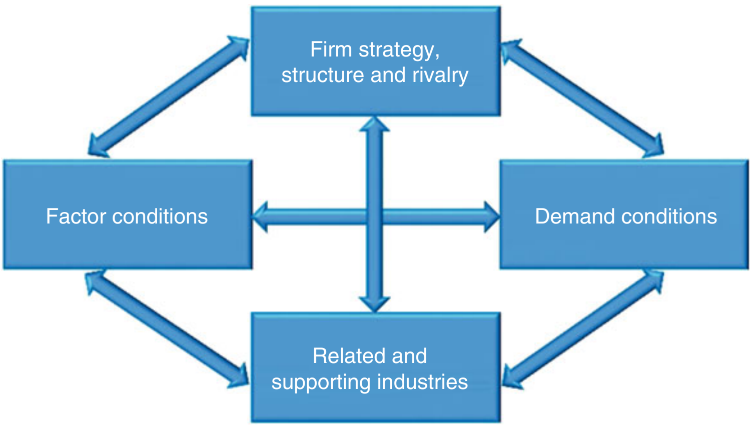

Fig. 1 Porter's diamond model of competitive advantage

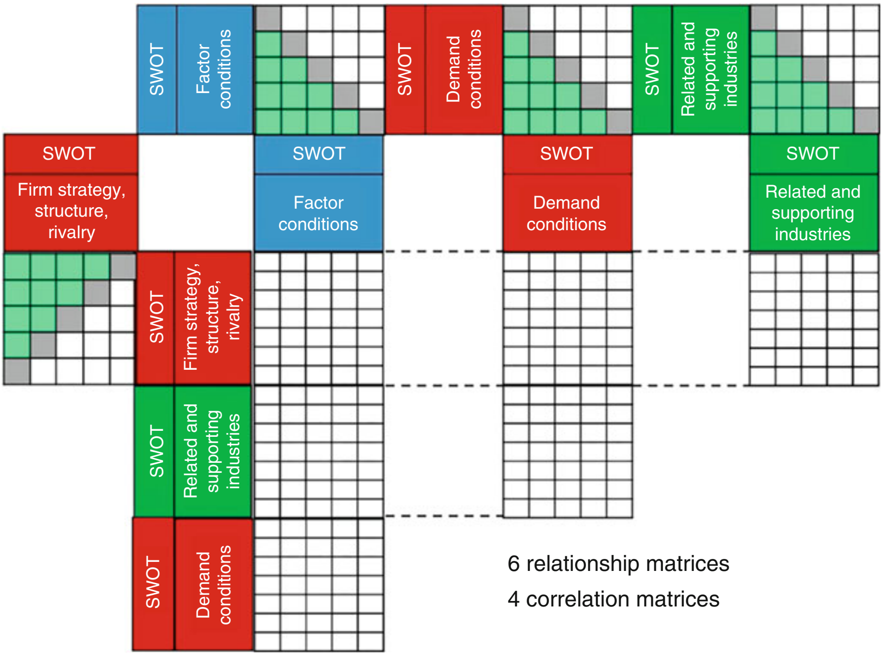

Fig. 2 The new representation of Porter's diamond

paper for building-up in a systematic way the Porter's diamond framework consists of six steps (see Fig. 2).

Step 1: Build-up the blocks of the diamond. Use SWOT framework [10] to position each component of the blocks into the following categories: strength (S), weakness (W), opportunity (O), threat (T). By presenting the components of the blocks as SWOT elements, an enhanced perspective of the competitive advantage is revealed. Moreover, action plans could be better formulated to overpass various gaps and drawbacks identified in the analysis.

Step 2: Build-up the relationship matrices between each pair of blocks from the Porter's diamond. Each relationship matrix reflects a link in the diamond (see Fig. 2). Thus, for the case illustrated in Fig. 2, six relationship matrices have to be constructed. Relations between components are expressed as levels of dependency using numerical values. The well-known practice from quality planning (Quality Function Deployment (QFD)) [11] is suggested for tackling this task. In this respect, the following levels of dependency could be seen: 0 no dependency; 1 weak dependency; 3 moderate dependency; 9 strong dependency; 27 very strong (critical) dependency [11].

Step 3: Build-up the correlation matrices between the components of each block from the Porter's diamond. Thus, four correlation matrices are constructed, one for each block of the diamond. The following types of correlation could occur for each pair of components: 0 no correlation; + or ++ positive correlation; – or – negative correlation.

Step 4: Analyze the results in the relationship matrices. All strong and very strong dependencies of the combinations W-W; W-T; T-W; T-T are with priority subject to innovations to overpass major drawbacks. TRIZ method [12] or other tools, such as sigma-TRIZ [13], is considered to tackle innovation in a structured way.

Step 5: Analyze the results in the correlation matrices. Negative correlations indicate places for innovations. TRIZ method is considered in approaching conflicts.

Step 6: Build-up the action plan by formulating innovation projects to the problems identified at step 4 and step 5. Projects could be prioritized. In this respect, some additional tasks should be performed. This paper suggests the followings: a) allocate an impact index to each component of the blocks (e.g. use a scale from 1 to 10; use the AHP method [7]; etc.); b) calculate the local value weight of each component in each relationship matrix using the impact indexes and the dependency levels; c) for each pair W-W; W-T; T-W; T-T a priority can be associated by summing the local value weights and multiplying the result with the value of the dependency coefficient. The same approach can be considered to prioritize innovation projects in the correlation matrices.

In a mathematical formulation, points at step 6 look like in the followings. Considering the block X, the impact indexes are denoted $R(\mathrm{X})_i$, $i = 1, .., n(\mathrm{X})$, where $n(\mathrm{X})$ is the number of components of the block X. Considering the pair of blocks X-Y, the dependency coefficient between the component $\mathrm{C(X)}_i$ and $\mathrm{C(Y)}_j$, $i = 1, .., n(\mathrm{X}), j = 1, .., n(\mathrm{Y})$, is denoted with $a(\mathrm{X\text{-}Y})_{ij} = a(\mathrm{Y\text{-}X})_{ji}$. The value weight of $\mathrm{C(Y)}_j$ is $\mathrm{W(Y\text{-}X)}_j$, $j = 1, .., n(\mathrm{Y})$, and is calculated with the formula:

$$\mathrm{W}(\mathrm{Y}-\mathrm{X})_j = R(\mathrm{X})_i \times a(\mathrm{X}-\mathrm{Y})_{ij}; i = 1, .., n(\mathrm{X}), j = 1, .., n(\mathrm{Y}). \tag{1}$$

The value weight of $\mathrm{C(X)}_i$ is $\mathrm{W(X\text{-}Y)}_i$, $i = 1, .., n(\mathrm{X})$, is calculated with the formula:

$$\mathrm{W}(\mathrm{X}-\mathrm{Y})_i = \sum_{j=1}^{n(\mathrm{Y})} R(\mathrm{Y})_j \times a(\mathrm{Y}-\mathrm{X})_{ji}; j = 1, .., n(\mathrm{Y}), i = 1, .., n(\mathrm{X}). \tag{2}$$

If the number of attributes from the diamond are extended (e.g. government, chance, knowledge absorption and innovation capability, culture, workers, entrepreneurs, politicians, professionals, bureaucrats), the number of matrices from Fig. 2 will be extended accordingly.

3 Case Study

To identify the competitive advantage of an IT cluster in the N-W region of Romania and to formulate an appropriate development strategy, the methodology introduced in Sect. 2 has been considered. Figure 3, shows the relationship matrices for the IT cluster under consideration. Blocks' components are grouped into affinity sets, as S,

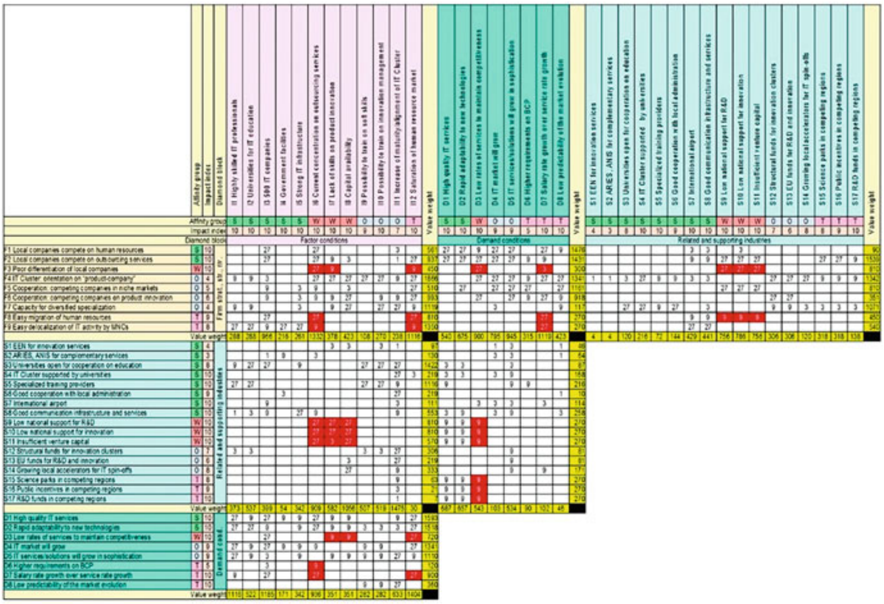

Fig. 3 The diamond of competitive advantage for the IT cluster under consideration

W, O and T. Figure 3 also highlights the impact index of each component. The impact index was allocated by the team members involved in the analysis based on their subjective appreciation. Each element from the four blocks of the diamond has associated three local value weights (see Fig. 3). By adding these local values, a global value weight is associated to each element. For example, the element "F1. Local companies compete for human resources" has the global value weight 561 + 1478 + 90 = 2129. The element "S11. Insufficient venture capital" has the global value weight 570 + 270 + 756 = 1596, etc. Thus, it is possible to elaborate a list with priorities for each set S, W, O and T. In each relationship matrix, some boxes are highlighted. They display the critical points, where various elements of W and T are interacting. Using this information, decision makers can measure the scale of criticality in the ecosystem and thus, have the possibility to elaborate a development strategy in a much more effective way. For example, the above mentioned element F1 has no critical points with other elements, whereas the element S11 has six critical points. This means, S11 requires at least six innovative measures to solve various conflicts in the ecosystem.

In this case study we see 38 critical points (Fig. 3, red highlighted). They are actually those zones in the ecosystem where innovation projects should be considered with priority in order to improve the competitive advantage of the IT cluster. For example, the link between "Firm strategy, structure and rivalry" and "Demand conditions" shows four critical issues. They are: (Problem 1) Poor differentiation of local companies—Low rates (costs) of services to maintain competitiveness ($P = 27 \times 300 \times 900 = 729 \times 10^4$); (Problem 2) Poor differentiation of local companies—Salary rate growth over the service rate growth ($P = 3 \times 300 \times 1119 = 100.71 \times 10^4$); (Problem 3) Easy migration of human resources—Salary rate growth over the service rate growth ($P = 27 \times 270 \times 1119 = 815.751 \times 10^4$); (Problem 4) Easy delocalization of IT activity by MNCs (i.e. multinationals)—Salary rate growth over the service rate growth ($P = 27 \times 270 \times 1119 = 815.751 \times 10^4$). Thus, the order of approaching the four challenges would be: (4)–(3)–(1)–(2).

In the case of (Problem 1), the challenge looks like: What solution(s) should the IT cluster apply such as to increase the service rates and differentiation of IT companies? TRIZ Contradiction Matrix [12, 14], with adaptations for managerial problems (TRIZ-M) [15] is experimented in this paper to support the innovation process. A software tool is used in this respect [15]. Inspirational elements to interpret inventive principles are also considered from works such as [1, 16–18]. It provides some generic guidelines to search for innovative solutions. To increase service rates, TRIZ suggests to increase the local quality.

Thus, companies in the cluster should learn how to make the transition from homogeneous processes/structures to heterogeneous processes/structures such to provide high quality for niche applications. To increase differentiation of the cluster's companies, TRIZ suggests the following vectors of innovation: periodic action, translation into a new dimension, convert harm into benefit. An innovative solution in the spirit of these vectors is to establish intra-companies consortia for each application field, with clear dedicated teams and organization (e.g. companies with expertise in financial area will form a dedicated consortium; those with expertise in health will form another dedicated consortium, etc.).

For (Problem 2), the task is: What solution(s) should the IT cluster apply such as to break the rule "salary rate above service rate" with (or without) higher differentiation of IT companies? For the case of productivity increase without acting on company differentiation, TRIZ suggests the following vectors of innovation: increase local quality, convert harm into benefit. It is actually the situation met at problem 1, thus the same innovation projects should be considered. For the case of productivity increase with a higher differentiation of the company, TRIZ-M shows: translation in a new dimension, replacement of the traditional system, keep the potential, use an intermediary system. These vectors lead to the idea of converting from service-company to product-company. Thus, the IT cluster should undertake actions to support more companies to move towards proprietary product-service innovations.

For (Problem 3) the challenge is: What solution(s) should the IT cluster apply such as to break the rule "salary rate above service rate" even if human resources can easy migrate in other IT clusters (abroad)? For this problem, TRIZ suggests the following vectors of innovation: dynamicity, translation into a new dimension (multi-level), composite structures. These vectors can be translated into several solutions such as the next three. One key is to develop more intrapreneurship initiatives for highly skilled professionals. Another key is to establish partnerships between cluster companies for intra-companies mobility of people for various projects, with inclusion of success bonuses. The third key is to setup a network for bringing professionals from Eastern countries (e.g. Moldova, Ukraine, etc.) on short and mid-term working schemes.

For (Problem 4) the challenge is: What solution(s) should the IT cluster apply such as to break the rule "salary rate above service rate" even if MNCs can disturb this effort if they localize their IT offices in the cluster's hub? There is no restriction to approach this problem. According to TRIZ, several vectors of innovation are recommended, as follows: transformation of system properties, reconfigurable construction, use of permeable units, use different units with different expansion/contraction levels, etc. These vectors suggest actions to enhance cooperation between companies in the cluster such as to formulate competitive offers even for outsourcing services. Also, they suggest a major focus on reorienting cluster companies from outsourcing services to proprietary product-service systems, such as to increase the productivity rate.

The space limitations of the paper restrict the introduction of all four correlation matrices from Fig. 2 for this case study. Therefore, only one of these matrices was selected for exemplification, specifically the one which refers to "demand conditions". Details are illustrated in Fig. 4.

A lot of negative correlations are highlighted in this case. Among them, two are of high priority. The first position is occupied by "salary rate grows over the service rate" versus "low rates of services to maintain competitiveness". The second position is employed by "higher requirements on BCP" versus "low rates of services to maintain competitiveness". In both cases, the eco-system moves towards a saturation level, even with organizational and process innovations. This shows that a long-term strategy in keeping the core business model of outsourcing services is not beneficial

			D1 High quality IT services	D2 Rapid adaptability to new technologies	D3 Low rates of services to maintain competitiveness	D4 IT market will grow	D5 IT services/solutions will grow in sophistication	D6 Higher requirements on BCP	D7 Salary rate growth over service rate growth	D8 Low predictability of the market evolution
D8 Low predictability of the market evolution	T	10	++	++	++					
D7 Salary rate growth over service rate growth	T	10		++	--	--				+
D6 Higher requirements on BCP	T	5	++		-	--	+			
D5 IT services/solutions will grow in sophistication	O	9	-	++	--	--		+	+	
D4 IT market will grow	O	9		+	-				-	
D3 Low rates of services to maintain competitiveness	W	10	-	-		+	-	-	--	
D2 Rapid adaptability to new technologies	S	10	-		--	+	+	-	+	
D1 High quality IT services	S	10			--	+			+	
Impact index			10	10	10	9	9	5	10	10
Affinity group			S	S	W	O	O	T	T	T

Fig. 4 The correlation matrix for the block "demand conditions"

for the sustainable development of the IT cluster. Thus, a medium-term strategy to direct the IT cluster from outsourcing services to proprietary product-service solutions, either on individual and/or collective initiatives is necessary.

This case study outlines the advantages of the proposed framework to display the critical issues of competitive advantage of a given ecosystem, to quantify them and to prioritize them. By inducing a special way of thinking and analysis, the dimension of innovation can be quantified. All these issues were not possible in the traditional application of Porter's diamond. We can enhance the framework with governmental policies, as well as with patterns of evolution such as to model the chance of bringing future innovations in the ecosystem. These additional pieces increase the value added of the proposed framework.

4 Concluding Remarks

This paper demonstrates that the links between the blocks in the Porter's diamond model, mostly neglected in the previous researches and practices, should be very seriously taken into account such as to reveal a comprehensive picture of the business environment. A depiction of these links into detailed relationships and correlations between the diamond blocks reveals a huge space of challenges and innovation opportunities. Links are actually "roads" with a number of tracks equal with the number of elements in the blocks of the diamond. Expressing the diamond's blocks as SWOT blocks is an effective approach of the competitive space of manifestation and somehow this way displays the magnitude and complexity of innovation efforts.

Identification of mature solutions to various conflicting issues that exist in the body of these links is the most provoking task for experts and decision makers. Supporting the conceptualization process of these solutions with innovative problem solving tools is truly beneficial. To these advantages of the proposed methodology, at least one more could be added: the revelation of the dynamic (temporal) dimension of the analysis.

Future researches to polish the methodology introduced in this paper are possible. They include the consideration of more blocks in the diamond (e.g. government, culture, knowledge absorption, etc.), as well as refinements in defining values for the impact indexes and dependency coefficients. Previous researches in this respect have explored fuzzy logic algorithms. However, a trade-off between practical relevance and scientific accuracy will have to be taken into account. Nevertheless, more studies on the dynamic dimension of the Porter's diamond model would be welcome.

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TRIZ to Support Disruptive Innovation of Shared Bikes in China

Jianguang Sun, Kang Wang, Zhonghang Bai, Yu Wang, and Runhua Tan

1 Introduction

The technological innovation drives the change of the world in future. The TRIZ theory is used to solve technical problems, predict technologies in future, and quickly and effectively develop out new-generation products, which can play a key role in the improvement of competitive capabilities of any enterprise. The theory of technology evolution finally aims to technology forecasting. Since Schumpeter proposed technological innovation theory, plentiful scholars have continuously exploring technological innovation theories and practices and perfecting research on technological innovations. In 70s of 20th century, R.Nelson and S.Winter have founded the innovative evolution theory branch under the inspiration of the biological evolutionary theory [1]. Nelson thinks that one evolutionary system should include the innovative mechanism, selection mechanism and system search capability. The TRIZ theory founded by Altshuller includes the technical system evolutionism as the key content. He thinks that evolution of the technical system is not random and all systems will evolve to "Ideal final result(IFR)". Later plentiful scholars have supplemented and perfected evolutionary theory of the TRIZ technology, e.g. Evolution of Technique (ET) of Savransky [2], Guided Technology Evolution (GTE) of Fey and Rivin [3], Directed Evolution (DE) of Zusman et al. [4], and The law of system evolution of Petrov [5]. The concept of disruptive innovation (DI) was proposed by Christensen in 1997 and was a technological innovation theory, which was established after continuous perfection [6–8]. DI does not aim to improve product performance, but to introduce products whose performance is inferior to that of the approved product on the mainstream market. But some features of such product do not attract non- important users or new users. After development, these

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products can replace the approved products on the mainstream, so the enterprises of these products beat the enterprises on the mainstream market. Generally DI products feature low price, simplicity, small size and convenient use, or have additional functions to attract new customer groups. DI is the branch in the technology evolution path based on analysis on the evolutionary characteristics of the TRIZ technology [9–11]. The bike-sharing project has developed quickly in China. Till the end of 2016, total users of sharing bikes have reached 18.86 million in China. It is predicted that the users of sharing bikes will grow quickly in 2017 in China and total users will reach 50 million at the end of 2017. However, with the expansion of the market, numerous problems are found in the current products. This paper analyzes the current conditions and problems of the sharing bikes by using TRIZ and disruptive innovation theory as its extension, solves existing problems, and predicts technology development in future.

2 Methods

2.1 *Systematic Innovation by TRIZ*

TRIZ provides multiple tools to solve problems. One tool or multiple tools of the TRIZ may be used during solution of one practical problem. Figure 1 shows the TRIZ solution flowchart. This figure describes relation among different tools and problems in product innovation. The first step for TRIZ application is to describe specific problems, analyze and establish the functional model, conduct causal analysis and resource analysis, and finally select a solving tool. If any contradiction is discovered, the contradiction solution principle is used to solve it. If the problem is specific, but the solution is unknown, the effect will be used to solve it. For the new

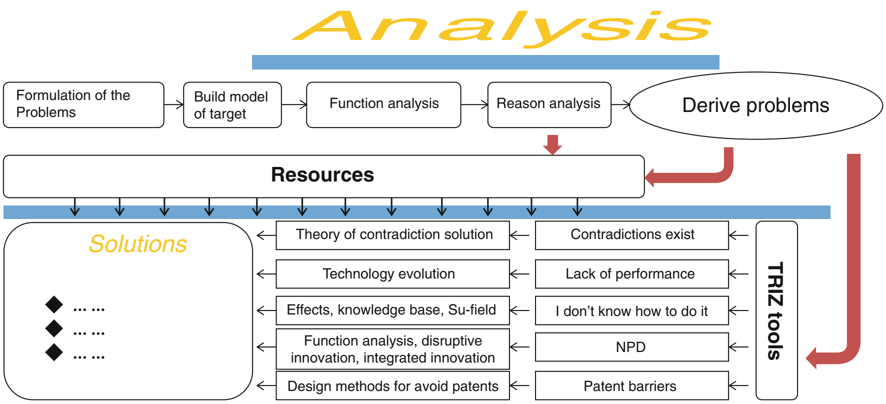

Fig. 1 Model of systematic process by TRIZ

product development, the disruptive innovation and technology prediction should be used. Generally the patent evasion technology can improve innovation efficiency greatly. Finally the obtained solutions can be evaluated to determine if it can satisfy the design requirements. If the requirements are satisfied, it can be further designed. On the contrary, the problem should be analyzed again.

2.2 Method for Roadmapping Disruptive Technical Opportunities

For long-term survival and development on a complicated, variable and competitive market, a company not only needs to keep Sustaining innovation, but also disruptive innovation. Only through disruptive innovation can an enterprise obtain advantages in competition and change the passive position in the competition. The sustaining innovation can only improve independent innovation capabilities of a company, but it is difficult to solve effective innovation problems of mature products. To develop effective new products, make a breakthrough over the product benefits, and thoroughly change the position of the company on the current mainstream market, the disruptive innovation should be used to find technical opportunities. Shown as Fig. 2, to predict innovation opportunities in the product maturity period, the technical opportunity search model is established based on the technology evolution branch process.

The implementation steps are described as follows:

1. **Select innovative objects and analyze technology maturity**
   Select innovative objects according to the product structure of the enterprise. First, analyze technology maturity of the innovative objects. The mature products face fierce market competition, so sustaining innovation is difficult to be kept and the performance/price ratio is not high, yet the implementation effect of the disruptive innovations is better. For the products during technology evolution exit period, the technologies of the difficulty function unit have approaches technology limit. The innovative resources for performance improvement are very deficient, so the Normal radical innovation is possible.
2. **Decomposition of technical system**
   Similar as the function structure of the product, the technical system of the product is composed of sub-systems at different levels. Each sub-system has complete system architecture and can be analyzed as a complete technical system. Generally a known technical system is decomposed by using the tree decomposition method in the figure. To analyze the technical system, the design restraints (volume, weight, price, operation convenience, energy consumption, etc.) are also listed into all sub-systems as the technical sub-system. With a series of decomposition process, finally multiple technical systems are generated [12, 13].

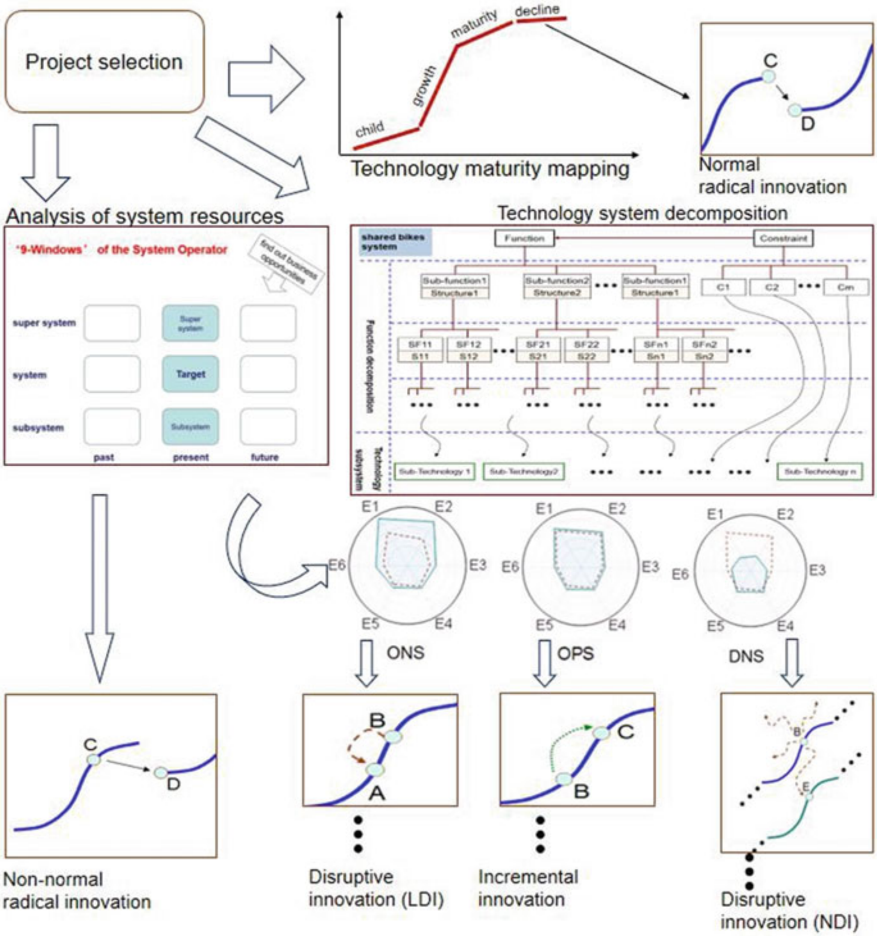

Fig. 2 Model of roadmapping disruptive technical opportunities

3. **9 Window establishment and resource analysis**
   For a specific market, establish the system 's 9-window model according to the sub-system, this system, super-system, past, present and future. Find resources in different areas and search technical opportunities. If the system includes potential evolutional resources, the technical opportunities of the Non-normal radical innovation can be implemented.
4. **Evolutionary analysis of technical sub–system**
   Compare current function states of different technical sub-systems with the evolutionary analysis result state of demands and draw the evolutionary state diagram of the technical sub-system. If the difficulty function unit related to the mainstream functions are over- evolved (ONS), the over-demanded mainstream functions can be reduced to implement Low-end Disruptive innovation (LDI). If

the new market user requirement (now or future) is not satisfied (DNS), the New market Disruptive innovation (NDI) can be implemented.

5. **Evaluation of design results**
Evaluate the innovative design results to determine if new technical contradictions are introduced, the cost is increased, and the market requirement is satisfied. After evaluation, the product enters the detailed design phase.

3 Technical Opportunities of Bike–Sharing Systems

In the past 10 years, the bike sharing system is used in more and more cities of the world. This system makes residents and tourists get bikes at any place in cities with less cost. After a bike is used, it is placed at another position. The sharing bike brings convenience to people, but it also gives rise to a number of problems, e.g. disorderly parking, delayed repair of failed bike, bike steal, potential safety troubles, etc. All problems bring market opportunities to new comers.

3.1 Solve Problems of Bike–Sharing Systems

The existing system has many problems to be solved, which can be solved with the flow in Fig. 1. E.g. shown as the Fig. 3, a sharing bike is different from a traditional bike in that it should be very reliable and be free of maintenance. A traditional pneumatic tyre is easy to leak air, so a maintenance-free solid tyre should be designed. But a solid tyre is heavy with higher riding resistance, resulting in physical contradiction, That is to say, the tyre should have the advantages of the solid tyre and

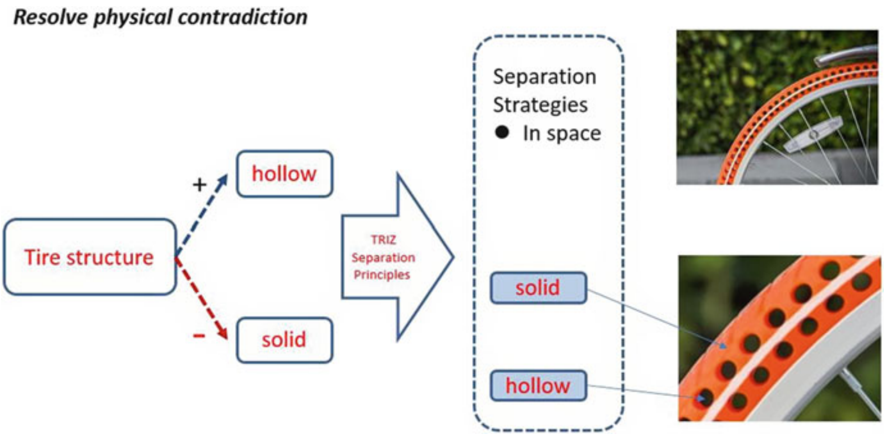

Fig. 3 Solve problem of tire by TRIZ physical contradiction theory

pneumatic tyre. With the space separation in the separation principle, the solid tyre is drilled to solve this problem.

3.2 9 Windows Analysis of Bike–Sharing Systems

Shown as Fig. 3, the sharing bike evolves from the old sharing bike with a pile. A sharing bike with a pile should be fixed to a fixed return site and the return sites are insufficient due to cost and city space restriction, so the bike-sharing system cannot quickly develop. As a super-system resource, with quick development of Internet, GPS, smart mobile phone and mobile payment, a sharing bike without a pile is possible. A sharing bike without a pile has an electronic lock sub-system with the GPS function. Such lock with a breakthrough technology is developed due to resource breakthrough of a super-system, driving the bike- sharing systems to evolve from a system with a pile to the system without a pile.

High-level artificial intelligent technology will be used in future supper-system resources, so mending sharing bikes by robots might be achieved. The development of the network charging technology in future will continuously supply power for current smart lock, so it can solve the disorderly parking problem of sharing bikes (Fig. 4).

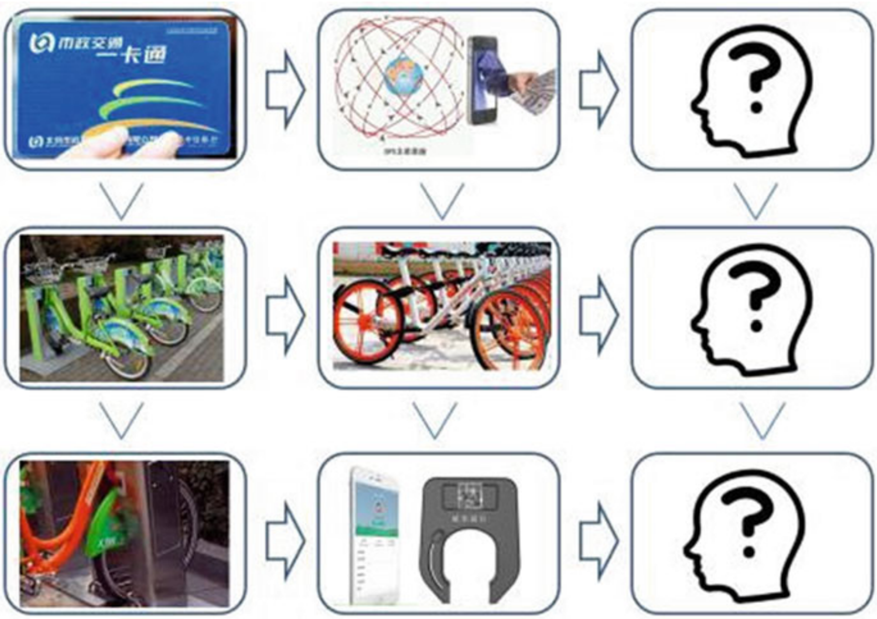

Fig. 4 9 Windows model of bike-sharing systems

3.3 Technical Opportunities Searching

Shown as Fig. 5, first, the bike-sharing technical system is divided into multiple technical sub-systems (the diagram only lists partial sub-systems and total 8 sub-systems are listed). To establish the system radar diagram and analyze requirements and evolution of all technical sub-systems according to the flow in the figure, the following technical opportunities can be obtained:

1. Reduce quantity of sharing bikes and improve their utilization rate. Now a large number of sharing bikes stay in some fixed area and affect traffic. No sharing bikes are available for some areas in urgent need of sharing bikes. To solve it, the flowing supply platform of sharing bikes should be established for supply on demand according to TRIZ dynamic principle.
2. Improve its adaptation capability to the environment, e.g. rainproof device, automatic saddle cleaning, protection against cold, etc.
3. Further solve loss and damage.
4. Add auxiliary driving and drive evolution of electric sharing bikes.
5. Customize bikes for different groups and enhance module and platform design of bikes according to the use area.

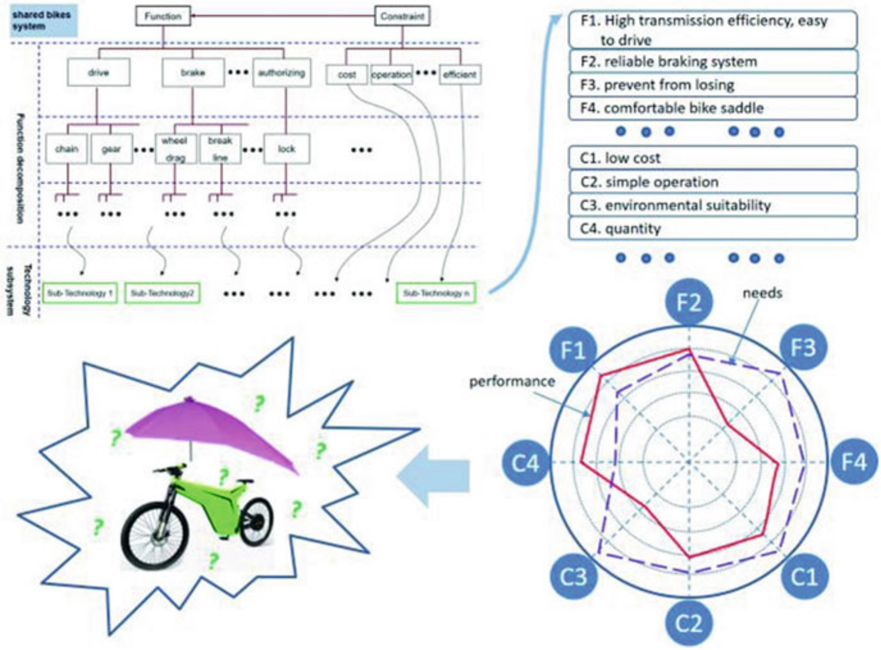

Fig. 5 Technological decomposition of bike-sharing systems

4 Conclusions

Many technical opportunities are available for sharing bikes, the outcome of technical evolution. How to recognize and explore these technical opportunities is a topic of significance. This paper studies and searches technical opportunities of sharing bikes by using traditional TRIZ theory and extended technical search and prediction models. This paper mainly studies the following contents:

- Establish the innovation process model of the TRIZ system.
- Construct technical opportunity search model of bike-sharing system.
- Decompose and analyze technical systems of the bike-sharing system and further give innovation implementation strategy.

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From Simulation to Contradictions, Different Ways to Formulate Innovation Directions

Sébastien Dubois, Hicham Chibane, Roland De Guio, and Ivana Rasovska

1 Introduction

Inventive design has often been described as a totally different approach than optimization ones. Such description could lead to the understanding that both approaches are not compatible. The authors aim at showing that optimization and inventive methods could be compatible and even more could benefit of each other. In [1, 2] the authors present the way they propose to define a continuum between both approaches. In [1], an approach combining both efficient optimization methods and methods of TRIZ, when no solution can be found out of the application of optimization methods, is presented. It is based on the use of ARIZ-85C, which limit is the identification of the prior problem to be solved. The identification of this problem is the result of the Analysis of Initial Solution, for which, the authors propose to use sequential experimentation. Sequential experimentation is a well-known sequence of different mathematical tools. The objective of this sequence is to quickly identify the main parameters enabling the satisfaction of the specs and the most appropriate range of values for these parameters. In [2], a general methodology to build the continuum is described, identifying the Pareto frontier as the limit of optimization approaches and also as a mean to identify contradiction. The Pareto frontier could have several benefits, on the definition of this continuum, the representation of the limits of optimization, another way to represent the contradictions, but also a mean to identify the way to search for innovations. This last point is the focus of this article, the author aim at illustrating than both optimization and inventive approaches (based on the elicitation of contradictions) could use the Pareto frontier to state innovative design directions. And the article will also illustrate that these directions are different, and thus complementary.

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2 Continuum Invention/Optimisation, Beyond the Pareto Front

TRIZ has been developed to propose patterns and rules for problem formulation and resolution in border of technical systems design. Thus, TRIZ methods propose several models to formulate the problem and better understand its root cause. Each of these models corresponds to a different level of abstraction. Whereas some of the models are only intermediary steps in the problem formulation process, other are used to enable resolution, and are linked to shaped databases of generic solutions. The objective of the different models is to enable a progressive understanding of the limits of the considered system and how it is possible to act on it in order to make it evolve. The most common models are the two models of contradictions, technical and physical ones. Khomenko, in [3], proposed a more precise definition of the problem, describing the technical parameters as evaluation parameters, and physical one as action parameter, as the physical contradiction indicates a mean to act on the system [4].

The physical contradiction focuses the problem on one single element of the system, which is defined as the core of the problem. According to TRIZ, a problem can always be formulated as a physical contradiction. Such a contradiction is defined as the requirement for one element to be in two contradictory states. A physical contradiction exists when one element of a system has to be in two contradictory states.

In [5], a relationship between the models of contradiction has been clarified and a system of contradictions has been presented to well clarify the role of each contradiction.

The limits of this "classical TRIZ" model has been demonstrated in [4] and a generalization of this system of contradictions has been defined and illustrated in [6, 7]. This generalized system of contradictions is not based anymore on single parameters, but on concepts built respectively with a set of Action Parameters for the Generalized Physical Contradiction and two sets of Evaluation Parameters for the Generalized Technical Contradictions, as illustrated on Fig. 1.

TRIZ contradictions are known to enable the application of resolution principles that enable to enlarge the domain in which solution concepts are searched. It can thus be recognized as the point of differentiation between optimization and inventive design approaches.

The Pareto frontier is the representation of all the possible instantiation of inputs (i.e. Action Parameter or set of Action Parameters) from which it is impossible to make any preference criterion (i.e. Evaluation Parameter or concept of Evaluation Parameters) better off without making at least one preference criterion worse off. The authors will define the link between the Pareto frontier and contradictions, by describing it in two dimensions, but it can be understood the same way by simply replacing Action Parameter by Set of Action Parameters and Evaluation Parameter by Concept of Evaluation Parameters.

Thus the Pareto frontier could be recognized as a graphical representation of a system of contradictions, as illustrated in Fig. 2. The points that are above the Pareto frontier are points that are at least dominated by one point, which means that at

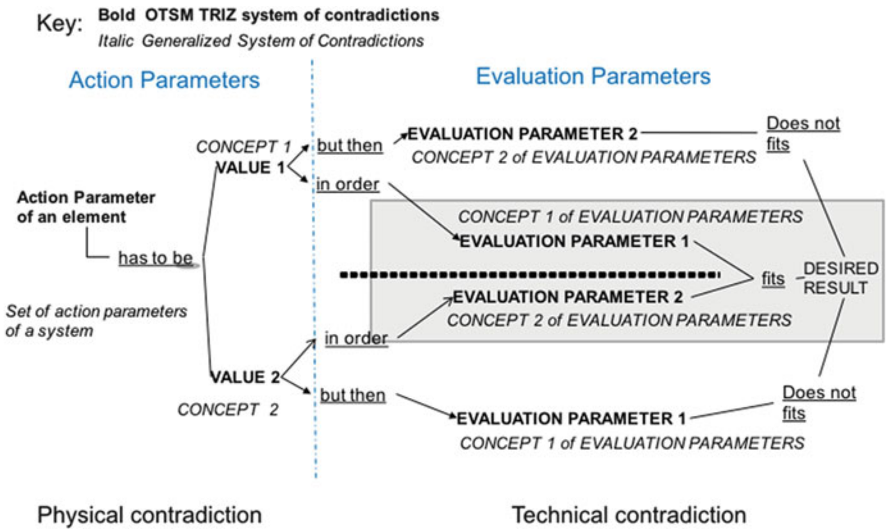

Fig. 1 OTSM-TRIZ system of contradictions and generalized system of contradictions

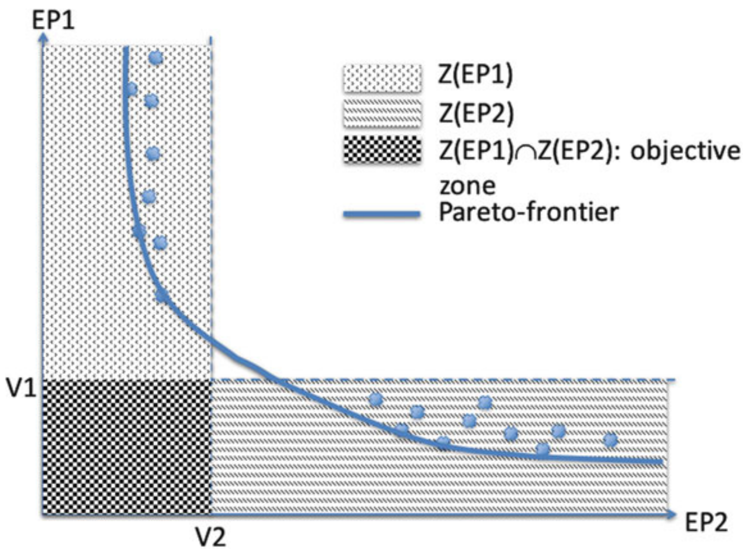

Fig. 2 The Pareto frontier

least one point has better values for the two evaluation parameters. The points that are on the Pareto frontier are points that are dominated by no other reachable points. It means that if a point is better on one of the two evaluation parameters, this second point will be worse for the second evaluation parameter. The desired result is any point that will satisfy both parameters, so any solution will be in the zone Z(EP1)∩Z(EP2).

Based on these definitions, one can recognize that considering two points of the Pareto frontier, one in Z(EP1) and the second in Z(EP2) directly enables the formulation of a technical contradiction. Identifying the Action Parameter that impact the increasing of one Evaluation parameter, and then the decreasing of the second one, directly enables the formulation of the System of Contradictions.

3 Optimization Approaches

Multi-objective optimisation is an area of multiple criteria decision making, that is concerned with mathematical optimization problems involving more than one objective function to be optimized simultaneously. Multi-objective optimization has been applied in many fields of science, including engineering, economics and logistics where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives.

In general, the problem of multi-objective optimization is posed as follows:

$$\begin{array}{l} \underset{x}{Minimize}\;\; f_{obj}(x) = \left[f_{(obj)1}(x) + f_{(obj)2}(x) + \cdots + f_{(obj)k}(x)\right]^{T} \\ subject\;\; to\;\; g_{j}(x) \leq 0, \quad j = 1, 2, \cdots, m \\ h_{l}(x) = 0, \quad l = 1, 2, \cdots, e \end{array} \tag{1}$$

where k is the number of objectives functions, m is the number of inequality constraints and e is the number of equality constraints. $x \in E^n$ is the vector of design variables where n is the number of independent variables x_i and $f \in E^k$ is a vector of k objective functions $f_i(x)$.

The most common approach to multi-objective optimization is the weighted sum method [8]. It transforms the multi-criteria function to a single criterion function through a parameterization of the relative weighting of the criteria.

In this condition, the minimization of Eq. (1) is Pareto optimal [9]. Some applications may involve maximization of one or more objectives, which can be re-formulated by multiplying by "−1" or taking the reciprocal (while ensuring that the denominator does not become zero) as objective to be minimized.

Finally, the genetic algorithm (GA) method for multi-objective optimization is used to solve the problem described in Eq. (1). Genetic algorithm was first introduced by John Holland [10, 11]. This searching process simulates the natural evolution and turns out to be an intelligent exploitation of a random search. The potential of a candidate solution is determined with respect to the objective function of the optimization problem under consideration. Generally, the GAO mechanism consists of three fundamental operations: reproduction, crossover and mutation [12–14].

4 Application for Cutting Process

The objective of this application is to optimize the cutting process during machining of AISI 52100 steel. Multiple objectives (i.e. Evaluation Parameters) are simultaneously taken into consideration like the surface roughness (*Ra*), and the productivity measured by the metal removal rate (*Mrr*). The selected machining parameters have been investigated using full factorial Design Of Experiments (D.O.E.) for three Action Parameters: the cutting speed (Cs), the depth of cut (*Doc*) and the feed rate (f) as presented in Table 1. The relationship between Action and Evaluation Parameters were developed by using multiple linear regression analysis (MLR) and first-order empirical models were obtained. Analysis of variance (ANOVA) was employed to check the validity of the developed models within the limits of the factors that were being investigated and to test the significance of the above parameters. Thus, the obtained empirical models have been used to determine the optimal machining parameters with multi-objective optimization method based on weighting factors and genetic algorithm optimization method.

In this study, the multi-objective optimization quantitatively determines the optimal relationship between cutting parameters *Doc, f, Cs* and the selected responses or objectives functions: surface roughness (*Ra*) and metal removal rate (*Mrr*). The most common approach to multi-objective optimization is the weighted sum method. It transforms the multi-criteria function to a single criterion function through a parameterization of the relative weighting of the criteria. Thus, the problem can be stated as minimize:

$$F_{obj}(Doc, f, Vc) = \sum_{p=1}^{P} \alpha_p f_{(obj)p}(Doc, f, Vc) \qquad (2)$$

It is assumed that the factors $0 \leq \alpha_p \leq 1$ with the condition $\sum \alpha_p = 1$ are chosen from the application to optimize. In this condition, the minimization of Eq. (2) is Pareto optimal.

In Table 1, the set of the 27 experiments has been described, as the result of this Full Factorial D.O.E. and the results have been colored with the satisfaction or not of the defined objectives, which are: $Ra < 2$ *and* $Mrr > 200$.

The Table 1 illustrates that no satisfying result can be obtained out of the simulation. In the case of multi-objective optimization, the weighting factors were chosen in eq. (1) from the objectives under considerations.

The considered multi-objectives are the minimization of the surface roughness (*Ra*) and the maximization of the productivity (*MRR*) simultaneously. Table 2 shows that optimization under considerations of all objectives does not provide a solution satisfying any of the evaluation parameters.

If representing the points of the experiments of Table 1 and building the Pareto front of these experiments, as illustrated in Fig. 3, one can recognize that no experiment satisfies the desired result. The point proposed by the multi-objective

Table 1 Full factorial design of experiments

run	Cutting parameters			Selected responses	
N°	*Doc (mm)*	*f (mm/rev)*	*Cs (m/min)*	*Ra (µm)*	*Mrr (cm^3/min)*
27	1	0,15	100	0,484	15
24	1	0,15	200	0,457	30
18	1	0,15	300	0,511	45
26	1	0,3	100	1,793	30
23	1	0,3	200	2,049	60
17	1	0,3	300	2,054	90
25	1	0,45	100	3,442	45
22	1	0,45	200	3,652	90
16	1	0,45	300	3,988	135
9	1,5	0,15	100	0,856	22,5
21	1,5	0,15	200	0,598	45
15	1,5	0,15	300	0,645	67,5
8	1,5	0,3	100	3,082	45
20	1,5	0,3	200	1,967	90
14	1,5	0,3	300	2,516	135
7	1,5	0,45	100	4,864	67,5
19	1,5	0,45	200	3,537	135
13	1,5	0,45	300	4,466	202,5
6	2	0,15	100	1,32	30
3	2	0,15	200	1,178	60
12	2	0,15	300	1,203	90
5	2	0,3	100	2,921	60
2	2	0,3	200	2,67	120
11	2	0,3	300	2,393	180
4	2	0,45	100	6,549	90
1	2	0,45	200	5,472	180
10	2	0,45	300	5,811	270

optimization is also not satisfying. Neither of these two optimization approaches (Full DoE and multi-objective optimization) are enabling to fit the desired result.

These results lead to consider that aiming to satisfy the initial objectives require to find a new model of the system, thus to go towards inventive design. This will be discussed in next part.

This experimental study was realized at the Center for Studies and Research on Cutting Tools (CEROC), Laboratory of Mechanics and Rheology (LMR), it was

Table 2 Multi-objectives optimization

Optimization	*Doc (mm)*	*f (mm/rev)*	*Cs (m/min)*	*Ra (um)*	*Mrr* (cm^3*/min)*
Ra/MRR	1.99	0.24	299	**2.5**	**148**

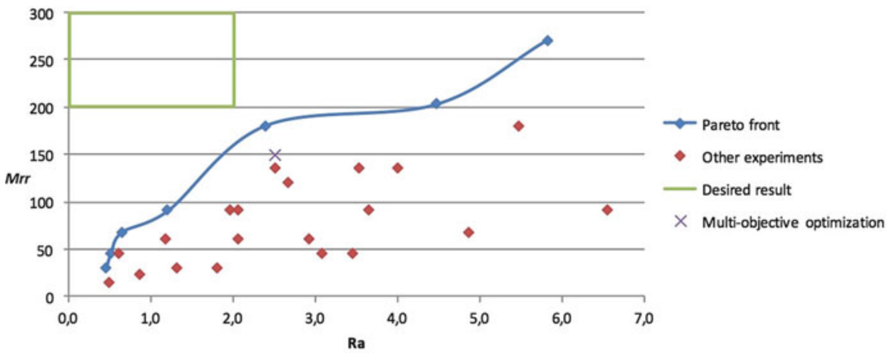

Fig. 3 The Pareto front out of the full factorial design of experiments

completed in the framework of Chibane's thesis [15]. The aim of this study, was the optimization of cutting parameters during turning 100C6 steel [16, 17].

5 Results and Discussion

As illustrated in previous part, the optimization approaches do not able to fit the defined objectives. So, it is required to use alternative methods to re-design the system, and thus propose innovation directions. The analysis of the data enable to propose such innovation directions, the easiest way to do so is to consider the influence of each action parameter. This analysis is presented on Fig. 4.

One can consider on Fig. 4 that both *Doc* and *Cs* have the same influence on the objectives: if *Doc* (or *Cs*) increases then the Pareto evolves to the objective zone. Thus the classical conclusion is to consider as an innovation direction the resolution of the problem: "How to increase *Doc* (or *Cs*)?". But such formulation of the innovation direction do not gives any clue for the search of solution. Thus, a third direction could be considered, through the analysis of the influence of the feed rate (*f*) on the Pareto front. One can easily consider on Fig. 4c) that if f is less than 0.30, then *Ra* is satisfies. On the contrary, in order to satisfy *Mrr*, it is necessary that *f* is equal to 0.45. The physical contradiction is then obvious, *f* has to be less than 0.30 to satisfy *Ra* and *f* has to be 0.45 to satisfy *Mrr*. The interest of this analysis is that TRIZ separation principles provides way to solve this problem. And the systemic separation enables the experts of the domain to recognize a solution, by proposing to design two cutting tools in parallel, each will have low speed, but the process will double its speed.

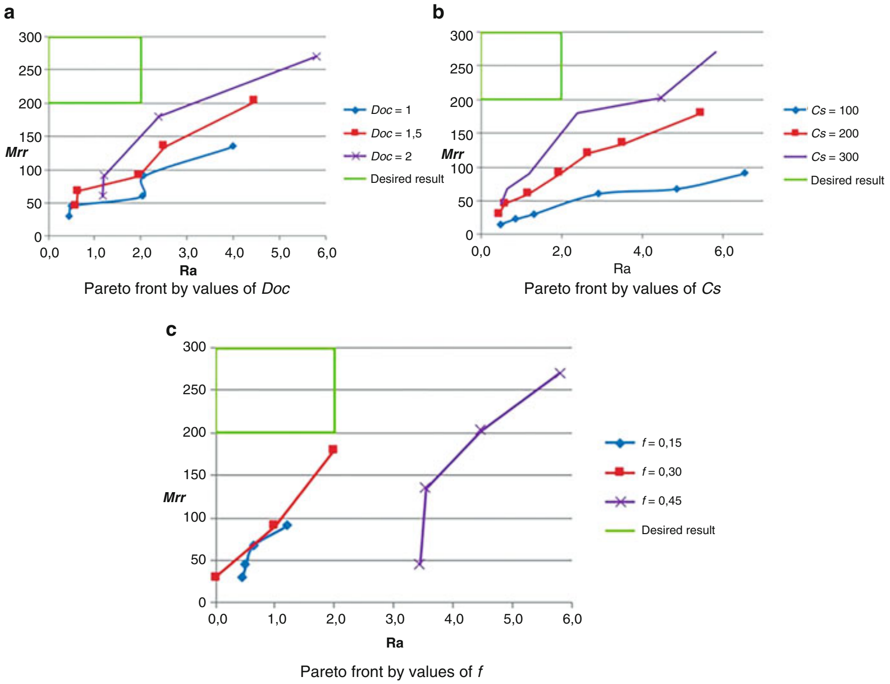

Fig. 4 Pareto front by action parameters

The authors aim at illustrating through this example that it is possible to consider inventive and optimization approaches through a cross fertilization point of view. In the treated example, the optimization approaches enable to automatically define the limits of the initial model (the Pareto front) and also to formulate the system of contradictions. And, of course, the contradiction and the TRIZ separation principles enable to go beyond this Pareto front.

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How Problems Are Solved in TRIZ Literature: The Need for Alternative Techniques to Individuate the Most Suitable Inventive Principles

Yuri Borgianni, Francesco Saverio Frillici, and Federico Rotini

1 Introduction and Background

Creativity is one of the key elements of the design process, which strongly affects the innovativeness of the related outcomes. Suitable means for stimulating creativity, especially during the early design phases, improve the whole product development process. Among the several tools available in literature, the ones belonging to the TRIZ body of knowledge are widely acknowledged as powerful aids for supporting and stimulating the creative thinking process. Such an assertion is supported by the experimental investigations that demonstrate the effectiveness of TRIZ in supporting the systematic ideation process [1], which appear in the literature more and more often. Furthermore, TRIZ has become nowadays a consolidated and reliable educational means for improving the creativity of engineering students and their capability of developing and implementing novel ideas [2].

Notwithstanding the empowerment of the design process enabled by TRIZ, one of the most criticized aspects refers to the extremely vast body of offered tools and techniques. This is frequently considered a severe limitation [3], since practitioners are not properly supported in the choice of the most suitable tool to face a specific problem—this is even more troublesome for unskilled users. In particular, [3] stresses the lack of standardized procedures to individuate proper tools, which makes the application of TRIZ difficult for practitioners. In other terms, the availability of a wide set of creative instruments might make the design process inefficient if users cannot identify the most appropriate ones in a quick and reliable way.

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Thus, the usefulness of such a large set of tools is still an open research question for scholars. Different proposals to sort TRIZ body of knowledge have emerged in the literature, but the prompts are still insufficient to standardize the employment of TRIZ. Moehrle [4] contributed to the goal by surveying 40 cases of TRIZ implementation in companies. The results showed that the whole set of TRIZ tools was not exploited and only few combinations of techniques were frequently observed. In the last few years, some contributions stress the need to provide a better understanding about the usability of TRIZ within the design process, which is still an open issue [5]. For instance, [6] suggests a classification framework of TRIZ techniques based on their potential role with respect to various engineering design activities. From a slightly different perspective, [7] characterizes Inventive Principles (IPs) according to the system's ontological domains (Function, Behaviour, Structure) for which their application makes the most sense.

The focus on IPs is not surprising, since they represent the most popular TRIZ technique according to recent studies [3, 8]. Actually, selecting the most appropriate IP is one of the most supported processes in classical TRIZ, thanks to the existence of the Contradiction Matrix. However, its reliability is often questioned [9] the present paper further argues the efficacy of the matrix too, as it will become more apparent in the following sections. This aspect has resulted in refinements of the original matrix [10], the redefinition of the IPs according to different distinction criteria [11] and alternative guidelines to overcome technical contradictions, for instance by analysing past successful solutions semantically [12]. However, an agreement on a solid and reliable procedure is far from being reached, as the above references demonstrate how the paid efforts give rise to a fragmented framework.

In this context, the authors believe that the TRIZ community could benefit from further contributions based on the observation of how problems are actually solved. Accordingly, the paper presents an empirical approach to investigate the recurrence of IPs to solve contradictions with reference to a classification framework based on ideality dimensions, and some preliminary results. In authors' view, it is possible to build upon the findings of the paper in order to support the selection of the most suitable IP(s) in the future.

2 Description of the Study

TRIZ handbooks and teaching material are rich in examples that demonstrate the rigour of the theory's way of thinking. The validity of the problem solving tools is often put forward through successful cases in which the use of TRIZ can be simulated. This reflects first Altshuller's efforts to generalize patterns that guide towards the inventive resolution of technical problems by examining patents. In other terms, the usability of TRIZ is justified a posteriori. Case studies in which TRIZ is effectively used to solve problems appear more seldom in the literature. However, the authors decided to investigate these "real" applications, because they are interested in investigating how TRIZ is actually used and not just which TRIZ instruments are consistent with solutions that have been achieved in different ways. In this framework, the authors were able to identify 42 case studies in which it is stated that TRIZ has benefitted the problem-solving procedure. These examples are included in TRIZ-related books, manuals and popular websites, which were individuated as sources of industrial case studies [13–18]. A first investigation concerned the use of IPs, since they are the most diffused instrument and therefore the ones for which a more robust selection procedure would result in major positive repercussions. This analysis was performed although IPs were not elicited in the specific examples or other TRIZ techniques have been employed to achieve the solutions—in several cases, the specific TRIZ heuristic was not even declared.

For each of the 42 solved problems, the study procedure was articulated as follows.

- The information about the existing problem was exploited in order to build a complete model of the contradiction (control parameter CP and the two evaluation parameters EPs).
  - All the EPs were attributed the most suitable engineering parameters present in the Contradiction Matrix, i.e. the 39 improving/worsening factors. In several cases, more than one suitable factor has been individuated.
  - All the EPs were characterized in terms of their reference to useful functions (UF), attenuation of harmful effects (HF) or limitation of resources consumption (RES). These acknowledged terms that form the basis of TRIZ expression of ideality were tested as an alternative for individuating appropriate IPs.
- The solutions to the given problems were characterized in terms of the most suitable IPs.
- The individuated improving and worsening parameters allow for a verification of the potential of the Contradiction Matrix to address towards the IPs that have been used in the practice. As the matrix is not symmetric, the worsening and improving factors were inverted as well and the test repeated.
- Regularities about the repeatability of contradictions expressed in ideality terms and corresponding IPs were examined.
- Overall evaluations about the frequency of IPs were performed.

The attributions and classifications, i.e. involved engineering parameters, UF/HF/RES categories and IPs, were agreed by all the three authors. In a specific case, a shared classification of the proper engineering parameter was not possible.

The information about the case studies and the agreed classifications is not included for space reasons. Interested readers can contact the authors for receiving the whole material, including the sources of each case study.

3 Results

3.1 The Reliability of the Contradiction Matrix in Problems Solved with TRIZ

This subsection is devoted to verify whether the Contradiction Matrix would have supported the definition of the solution to the contradictions present in the investigated examples. Overall, the matrix allowed the individuation of the employed IP in eight case studies out of the 41 ones that could be analysed (the worsening factor could not be identified once, as mentioned above). It is worth pointing out that whenever the authors have classified an EP through multiple engineering parameters, all the IPs emerging from the possible combinations in the matrix have been considered. In six out of the eight successful cases, the matrix would have addressed the assigned IP in both the combinations between improving and worsening parameters. In 3 out of the 33 unsuccessful examples, the corresponding cell of the matrix was empty, hence IPs could not be identified.

3.2 Using the Ideality Terms to Characterize Contradictions and Individuate Inventive Principles

The authors opted to classify the EPs according to the above terms of ideality in order to limit the number of categories of contradictions to be analysed, also because the quantity of available case studies was not particularly large. The scope was, as already stated, the capability of identifying regularities within the occurrence of IPs for certain kinds of contradictions. In these terms, the distinction between UF, HF and RES parameters is sufficiently shared and agreed at least in the TRIZ community.

In all the analysed 42 cases, at least an EP is to be classified as UF, i.e. a performance expected by the system. As a result, three classes of conflicts have emerged.

1. 21 contradictions between a UF-like parameter and a HF parameter, i.e. a factor that can be considered as an attempt to avoid undesired effects the system normally displays.
2. 11 contradictions between a UF-like parameter and a RES parameter, i.e. a factor that can be seen as the necessity to reduce the channelling of resources that enable the functioning of the system.
3. 10 contradictions between two performances that are ascribable to UF-like parameters.

The occurrences of IPs for the three subsets indicated in the above numbered list are qualitatively discussed in the followings.

In the most populated subset (UF vs. HF), five IPs appear more than once, i.e. 3 Local quality (four times), 5 Merging (twice), 13 The other way round (twice), 15 Dynamics (three times), 30 Flexible shells and thin films (twice). The IP 5 is found just in this subset of case studies, while the other mentioned IPs have been individuated also in other clusters. Hence, the IP Merging can be thought as a something specific for the contradiction UF vs. HF. The same conclusion could be somehow inferred for the IP Local quality, since it comes out much less frequently in the other two groups (once in UF vs. RES).

The subset UF vs. RES presents just two IPs that are found twice, i.e. 1 Segmentation and 25 Self-Service. The former is among the most diffused IPs, as it has been identified in all the three groups of conflicts. Also the latter is not specific for the discussed subset, because it mirrors also a problem ascribable to UF vs. HF. Therefore, it is hazardous to conclude whether any IP characterizes the subset UF vs. RES markedly.

The subset UF vs. UF is even more fragmented. Just the IP 15 appears twice and it is found in all the subsets. As a result, no IP can be considered specific for or particularly characterizing this subset.

Overall, three principles are present in all the subsets, namely 1 Segmentation, 13 The other way round and 15 Dynamics. Five other IPs are found in two subsets: beyond the already mentioned 25 and 30, it is possible to include in the list the IPs 4 Asymmetry, 34 Discarding and Recovery and 40 Composite materials. Overall, 19 IPs out of the 40 present in classical TRIZ have come out at least once.

3.3 Overall Frequency of Inventive Principles

Given the difficulties in characterizing the occurrence of appropriate IPs for classes of contradictions, their overall frequency in the 42 illustrative solutions was analysed. The authors believe that every TRIZ practitioner is aware of the uneven distribution of IPs, but specific studies are not known (at least in the authors' knowledge). In Fig. 1, the 19 found IPs are sorted according to their frequency. The picture shows the number of occurrences within the whole set of analysed examples (blue columns) and the cumulated percentage of cases in which the IPs would have supported the definition of the implemented solution.

It is worth noting that the most diffused 4 IPs can justify almost 50% of the described problem solutions. In order to facilitate reading, they are reported in the bullet list below, where their occurrence across the three classes of contradictions is specified although some information was partially provided above.

- The IP 15 Dynamics is present in all the classes of contradictions (three times for UF vs. HF, twice for UF vs. UF and once for UF vs. RES). Also in consideration of major number of cases described through UF vs. HF, the occurrence of this IP appears to be evenly distributed across the classes and hence very versatile.
- As already pointed out, the IP three Local quality, appearing four times for UF vs. HF and once for UF vs. RES, seems oriented to the solution of certain kinds of conflicts.

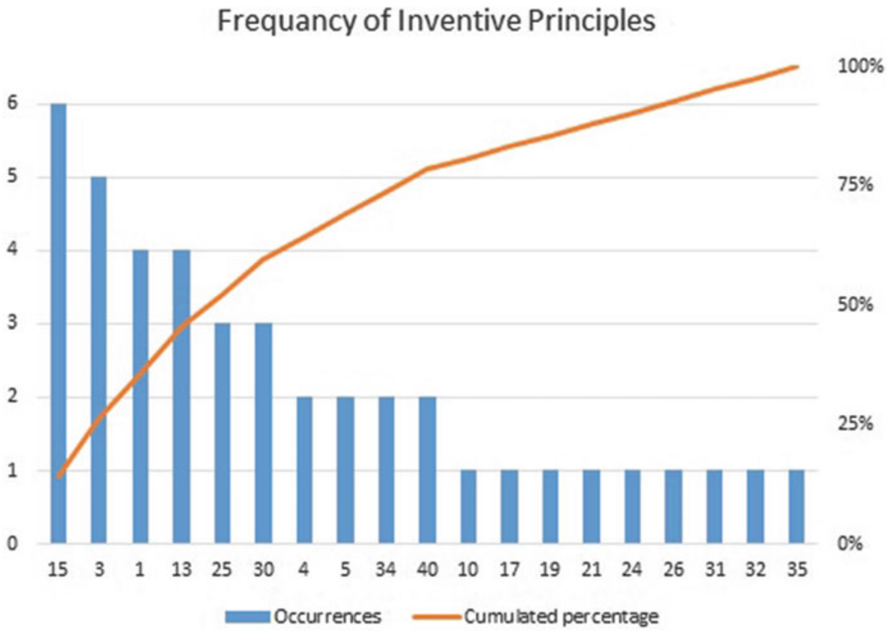

Fig. 1 Occurrences of IPs in the examined examples. In the abscissa are the numerical codes commonly associated to IPs

- The IP 1 Segmentation, coming out once for UF vs. HF and UF vs. UF, twice for UF vs. RES, seems the most appropriate for UF vs. RES contradictions if the size of classes is taken into account.
- The IP 13 The other way round has been recognized twice for UF vs. HF, once for UF vs. RES and UF vs. UF. Similar conclusions to those referred to the IP1 can be inferred at present.

4 Discussion and Conclusions

The present paper has shown an insightful investigation of the contradiction-solution relationship, given the criticism over TRIZ limited guidance towards suitable tools and the deficiencies of some instruments in terms of reliability. The objective is to contribute to a major understanding about the way problems are successfully solved in order to provide designers with better guidance and, at the same time, allow them to deliver creative results. The peculiarity of the paper is the analysis of few dozens of technical problems effectively solved with TRIZ. Many studies recognize some solution patterns compatible with the TRIZ body of knowledge, but the fact that any other design strategy might have been used can represent a bias. The main achievements are reported and commented in the followings.

The search for a meaningful (but still limited to show statistical evidences) number of problems solved by means of TRIZ was a time-consuming process. The divulgation of a larger number of real case studies could benefit the diffusion and popularity of TRIZ, which seem to be in a critical situation [19]. Future work will involve the individuation of a larger number of suitable examples anyway.

A procedure is proposed to investigate the contradiction-problem links. The authors experienced little problems in classifying EPs in terms of engineering parameters, reference ideality terms, as well as in characterizing the solutions according to IPs. The data lend themselves to different kinds of analyses or tests; for instance, CPs have been identified and this could represent a trigger to investigate separation principles.

The poor reliability of the Contradiction Matrix was largely confirmed. However, the alternative proposed classification of contradictions has resulted to date in limited capability to lead problem solvers towards appropriate IPs, though some interesting indications emerged for the UF vs. HF conflicts. Interestingly, at least an EP was to be classified as UF in every case study—this aspect is worth investigating further.

The exposed difficulties in supporting the selection of IPs bring the deterministic behaviour of contradiction-solution patterns into contention. On the one hand, multiple criteria to characterize the problem could be employed contextually in order to support the identification of an effective solution principle (see the present contribution and other cues discussed in Sect. 1). This characterization might be too time-consuming or, at least, give rise to an inefficient problem solving procedure. On the other hand, Fig. 1 shows that a few IPs might be leveraged effectively and irrespective of the faced problem, as they overall have high probability to suggest a valuable solution. This approach could undoubtedly oversimplify the rich and articulated design knowledge inherent to TRIZ [5].

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TRIZ to Support Creation of Innovative Shared Value Business Initiatives

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1 Introduction

Creating shared value (CSV) is a relative new concept that has captured attention of many companies' executives, as a more business-oriented alternative to the concept of corporate social responsibility (CSR). The concept of CSV was formulated and marketed by Porter and Kramer [1]. Shared value is a managerial strategy focused on creating measurable value for companies by identifying and addressing social problems that intersect business [1]. In other formulation, shared value is about searching for business opportunities in social problems. CSV is a concept that leads to economic value creation by social value creation [1, 2].

According to Porter and Kramer, shared value creation requires innovations into one or more of three possible directions [1, 3]. One way is to rethink needs, markets and products by developing new products for social needs [1, 2, 4]. The second way is to redefine productivity in the value chain by promoting new practices for better use of human resources, materials and partnerships [1, 5, 6]. The third path is to develop local clusters by improving innovation and productivity in local firms [1, 6].

To generate shared value, four elementary steps have to be followed: (1) identify the social issue to target; (2) make the business case; (3) track progress; (4) measure results and use insights to unlock new value [7]. There are various examples of companies that succeeded to create business value from social problems [5–7], but no scientific paper indexed in international databases such as ISI Web of Science, Scopus, Inderscience has reported till now a structured approach to define innovative shared value business initiatives.

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It is the purpose of this paper to introduce a methodology that systematically analyses the frame revealed by the shared value concept and unveils clear patterns of ideation towards businesses that can both solve social challenges and generate profit for companies. The research focus is upon all three areas where shared value creation can be manifested: product, value chain productivity and economic cluster development.

In order to introduce the methodology, the subsequent part of this paper is organized into the following sections: a section that analyses shared value concept for revealing possible contradictions and formulating innovative areas of intervention, a section that describes the methodology, a section where theory is put into practice, a section of discussions around the results from case studies, and a section of conclusions, critical analysis of the methodology and perspectives on future developments.

2 The Challenge of Creating Shared Value

Creating shared value is neither philanthropy nor actions of social responsibility [1]. CSV is a very profound concept that challenges intellectual and moral potential of business makers. It asks to formulate any business in a way in which its profit incorporates both societal advancements and faster growth of the business [5]. This paradigm is an invitation to outthink new business models, products and business environments.

The Cartesian mode of business thinking considers profit as the difference between price—in relation with the value perceived by customers—and the cost to produce that value. This is obviously true, but in this equation the societal value of the customer's perceived value is omitted. There are many products in the market with high commercial success, but with poor or no societal value; and in many cases, with negative societal value that worsens our society.

The non-linear mode of business thinking claims that it is possible to design businesses in such a way that they are capable to solve societal problems and/or improve societal welfare while simultaneously increase profitability. This requires smart innovations such as to increase profit as a result of more and differentiated value with lower costs; and/or promoting businesses that address societal problems in a profitable way; and/or creating business value networks that include in the economic activity local communities where products are going to be sold.

From this perspective, CSV is a totally different concept than CSR, as long as the last one is about a moral duty of a company to protect the general interest of society while doing businesses. From the perspective of CSR, companies should take actions for improving societal welfare and avoiding environmental degradation in the same time [8].

Advocates of corporate social responsibility claim that creating shared value is not a new concept, but only a rebranding of CSR [9, 10]. This divergent perspective might occur from the difficulty to capture the whole profoundness of the message inherited in CSV; that is, from the point of view of this paper, CSV is about businesses that have no negative influence on society's morals (both because of their types and of the modes they are conducted) and about more and smarter innovations such as to provide sufficient value to society without affecting a lasting survival of the business (e.g. capacity to sell at affordable prices for any particular market—including the emerging ones—but with sufficient profitability for company).

With these issues in mind, the CSV concept reliefs the following challenging issues for business creators and entrepreneurs:

1. How to create honest profit focusing on current societal problems while generating better welfare and more socio-economic opportunities for the envisaged community?
2. How to generate more value for customers at lower costs and sell this value at affordable prices such as even the low-end consumers to get a high value from the business?
3. How to involve consumer in the economic process of value creation such as to offer local jobs as a consequence of that business?

The three questions above mentioned have a correspondence in the TRIZ Contradiction Matrix [11]. This issue is highlighted below:

- Reduce "harmful" societal factors without diminishing "amount of substance"/money/profit
- Reduce "criticality" in society without affecting "amount of substance"/money/profit
- Increase "adaptability of the system" without affecting "amount of substance"/money/profit
- Increase "capacity/productivity" without increasing "effort" involved
- Increase "capacity/productivity" without affecting "strength" of the system
- Increase "volume" of advantages without affecting business "durability"/sustainability
- Increase "amount" of work done by local firms without affecting "reliability" of the system

The conflicting issues from above are further deployed into TRIZ Contradiction Matrix [11]. The pairs of TRIZ parameters are: 30-26; 35-26; 39-19; 39-14; 7-15; 26-27, as they are coded in TRIZ [11]. After systematization, results are visualized in the following list:

- AI1: Change system properties (flexibility, conditions, state, etc.)
- AI2: Reconfigurable construction and dynamicity
- AI3: Use permeable units
- AI4: Use "centrifugal forces" and cyclic actions
- AI5: Arrange parts in advance to act from the best position
- AI6: Use external motivators
- AI7: Exploit resonance
- AI8: Make the system asymmetric
- AI9: Composite structures

The generic inventive principles in the above list describe areas where ideas for CSV-driven businesses would be formulated. The open issue is how such generic areas of investigation can be particularized for various business domains. It is the purpose of the next section in this paper to highlight a possible path for achieving this target.

3 Design Methodology of CSV-Driven Businesses

The design methodology of CSV-driven businesses starts with the definition of the business domain. In theory, any business domain should be a generator of CSV; thus, any type of business could be taken into account in a CSV process. Illustrative examples of business domains are: software development, education, earth mining, beverage production, food production, transportation, showbiz, etc.

The next step of the methodology analyses into detail market segments that are addressed by that business and tries to understand their challenges in terms of more welfare and societal manifestation. "Go-to-gemba", as Japanese say, is a very powerful tool to identify societal problems in a given market segment [12]. For example, a PLM software producer that addresses its solutions to engineers might see a social problem in terms of spine and eyes health issues due to the fact that the target users concentrate too much on the screen and stay too much time on chairs in less ergonomic positions. In order to create shared value, the PLM software producer should provide some special accessories to the traditional software tool, such as anti-radiation glasses, pulse track smart sensors and alarming boxes against static stress, but also to design the user interface in such a way it is easy readable and pleasant to eyes, etc. If the interface is also optimized in terms of minimizing the steps for performing various tasks and recovery in case of mistakes, more shared value is introduced in the solution. If the users would be paid with different bonuses (e.g. free training) for valuable feedbacks to improve the PLM system, the level of shared value is further increased.

Once societal problems are identified, the areas of intervention that have been introduced in the previous section are mapped over company's product portfolio. At the intersection boxes between each product and each area of intervention, every societal problem in the list must be considered and ideas for CSV have to be formulated in the spirit of the suggested trend of those areas of intervention.

In order to enhance the basin of investigations, every identified societal problem will be deployed into new product ideas—keeping bordered the generic domain of expertise of the company—by means of a toolbox of disrupting vectors. These vectors can be collected from various methods and tools of creative thinking. In this paper, a toolbox consisting of ten disrupting vectors is introduced, namely: 1) activate resonance; 2) introduce neutral elements; 3) act against the wolf-pack spirit; 4) use centrifugal forces; 5) apply multi-level connections; 6) use asymmetry; 7) harmonize individual goals with collective goals; 8) consider financial feasibility with real options; 9) prisoner paradox; 10) shipwrecked paradox [13]. Prisoner paradox is about the exploitation of only existing local resources to solve a problem by intelligent rearrangement and use of those resources [13, 14]. The shipwrecked paradox is about the transformation of some local negative factors into positive factors by identifying hidden value networks [13, 14].

To give an extreme example, let us consider a company that manufactures missiles for supporting military fights in urban areas. The social problems with these kind of products are related to issues such as human injuries, people killing, destructions of buildings, sufferings for lost lives, etc. Application of the disrupting vector "activate resonance" would suggest the development of smart missile systems able to recognize civilians and capable to direct and concentrate the blast only on military targets. Application of the disrupting vector "introduce neutral elements" would suggest the development of smart missile systems capable to detonate only if they "feel" the presence of explosive chemical substances such as gun powder or others in the same range. Thus, injuries on civilians would be dramatically diminished in the conflict zones. Moreover, applying the disrupting vector "harmonize individual goals with collective goals", which means a space without conflict, the idea is that, besides developing smart missile systems, to invest in easy mountable, reliable and cheap camping solutions for civilians that are called to shelter in advance of a potential military incursion in an urban area. This would reduce the time necessary to solve a conflict, as well as the related costs.

New business ideas generated in the previous step are systematically analyzed for feasibility. In this respect, the following question-based framework is proposed:

Group A: Factual analysis

- Which are the basic resources you need to start?
- Which is the interest/motivation?
- Who else can be attracted in this business with no difficulty?

Group B: Emphatic analysis

- Did you identify all beneficiaries?
- Which is the value added for beneficiaries?
- How beneficiaries would react to this product?
- Would beneficiaries involve in product co-creation?

Group C: Critical analysis

- What barriers do you envisage in implementing the business (any kind of barriers)?
- Who would have the interest to block this business and why?
- From what sources it will be ensured business sustainability?
- What risks would be in place?

Group D: Benefit analysis

- How large is the market?
- What complementary businesses would be run?
- What new businesses would emerge and how large?

- How much sophistication?
- What about profitability level?
- What new businesses would occur from the results of this business?

Group E: Processual analysis

- What steps should be followed?
- Which would be the first steps?
- Who will be involved before starting the business?

Group F: Creative analysis

- What ideas do you have to overpass barriers?
- What leverage effects do you see?
- What new opportunities could be born?

For the last group of questions (Group F), TRIZ method can be further considered in order to formulate inventive solutions to the barriers that are identified.

4 Illustrative Example

To illustrate how the methodology works, two case studies from the IT industry are further introduced. Both companies included in these case studies are software development companies, with a special focus on software services.

In the first case study, an opportunity occurred in a public financed project where the goal was to mix the IT sector with the agriculture sector, in the attempt of setting up an emerging industry called agriculture 4.0. The market envisaged in the project covers the Balkans and Black Sea Region. This region is characterized by emerging economies. In this context, the company has investigated the possibility to develop a software system with application in agriculture. The target market consists of agro-food producers and consumers.

Face-to-face discussions with representatives from the two groups revealed several social problems. In the case of small farmers the major problem was related to unfair practices of the retailers in the public agro-food markets and supermarkets, which either oblige local farmers to sell their products at very low prices and/or block local farmers to showcase their products in the markets—their place being taken by intermediaries. Intermediaries raise prices and sell products of lower quality—mass produced in different places of the globe. Due to the lack of alternatives, consumers are somehow forced to buy poor quality and unhealthy products (with a lot of pests and other chemicals inside), while paying high prices—that exceed, in many cases, prices from Western countries.

Company's current portfolio is: P1: web applications; P2: database systems; P3: process management platforms; P4: financial management platforms. Table 1 shows the map between the generic areas of intervention and company's current product/service portfolio.

Table 1 Mapping of current product portfolio and areas of intervention

	P1	P2	P3	P4
AI1	SP1	–	–	–
AI2	SP2	–	–	SP2
AI3	–	SP1/SP2	–	–
AI4	–	–	–	–
AI5	SP1/SP2	–	–	–
AI6	–	–	–	SP1/SP2
AI7	SP1/SP2	SP1/SP2	SP1/SP2	–
AI8	–	–	–	SP2
AI9	SP1	–	–	–

Denoting with SP1 the social problem "no reliable retail channels" and with SP2 the social problem "poor quality/unhealthy products a high prices", and based on creative judgement of possibilities, some boxes in the matrix from Table 1 indicate where innovations would be considered for CSV solutions.

The map from Table 1 reveals points where different inventive vectors (AI1 ÷ AI9) can be applied on the current portfolio of the company to propose CSV-driven solutions. In principle, all boxes of the matrix can be investigated. Actually, all boxes have been investigated in this case study, too, but some of them have been finally removed due to the lack of innovative ideas. Examples of reading information from Table 1 are further given.

The box AI1-P1 applied on SP1 suggests the development of a web platform for small farmers where they can introduce information about their products. In this case, AI1 "change conditions" was interpreted as a new environment where farmers can promote their offers.

The box AI2-P2 applied on SP2 suggests the development of a mobile app where consumers can introduce and find information about prices of various products in different places, thus generating an indirect pressure for price regulation. In this case, the vector AI2 "reconfigurable construction and dynamicity" was the source of inspiration for the mobile app where consumers can be contributors themselves. The other boxes followed a similar stream of ideation, but details are not introduced here.

In order to enhance the searching area for new products, the toolbox of ten disrupting vectors has been considered for the two major social problems SP1 and SP2. Only some of the results are further introduced.

Thus, the application of "activate resonance" led to the idea of putting in direct contact small farmers and consumers from the urban areas using a web platform/ mobile app, thus removing retail intermediaries. Of course, this idea must be further elaborated to reveal the whole value chain of the new business.

Applying to this idea the disrupting vector "introduce neutral elements", the concept is enriched with the idea of including a quality certification body in the ecosystem, for issuing quality certificates, as well as online feedback of beneficiaries. Continuing the reasoning and adding the vector "act against the wolf-pack spirit", the solution was enhanced with the idea of allowing any producer to use the platform for free up to a certain level of trade, and then allowing to purchase customized vouchers. The vector “use centrifugal forces” suggested the opportunity to upload additional information for product traceability over its life time.

“Multi-level connectivity” induced the idea of setting up strategic partnerships with non-conventional channels of promotion, such as churches from the rural areas, associations of volunteers, etc. It has also shown the need to activate the value chain by including a customer care center, networks of door-to-door transporters, producers of smart refrigerating boxes for temporary storing of products, etc. “Asymmetry” led to the idea to allow consumers having the possibility of calling in advance (based on pre-paid vouchers and hidden identity) future products (types, quantities, qualities), such as producers might pro-actively act and start deals in advance (using the agro-stock web system).

Combining all ideas relieved both from Table 1 and from the use of toolbox of disrupting vectors, the vision of the new business looks like: “An agro-stock market using a web and mobile software system that puts in direct contact small farmers and urban consumers for direct procurement of agro-food goods, with online support, with possibility for just-in-time door-to-door delivery using a smart distribution and storing network, as well as with feedback loops for quality guarantees and highly competitive prices”.

In order to transcend the stage of business vision and formulate a reliable business model, the list of questions promoted by the methodology has to be further tackled. Results at this stage of the methodology are displayed in Table 2.

For the set of barriers highlighted in Table 2, TRIZ Contradiction Matrix was considered. Thus, the challenge in this case study is how to activate both producers and consumers to make deals using the dedicated web platform.

There are many web platforms where offer and demand meets for various products and services. TV marketing campaigns are usually considered in such cases for activating the two categories of stakeholders.

In this case, the challenge is to identify cheaper ways of marketing campaigns, but other issues are in place, too. For example, small farmers have poor skills to use web platforms and are reluctant to use them because they do not understand the system and the business model behind. Thus, support and guidance for producers is essential. Consumers, at their turn, should reach a critical mass in the incipient phase of business launching, such as to signal the existence of a market.

Application of TRIZ Contradiction Matrix to this case looks like: “area covered by dynamic elements” vs “effort spent to activate dynamic elements”. The related inventive principles are: “periodic action”, “change the transparency of the system” and “use additives to reveal parts of the system that are difficult to see”. Based on these guidelines, the following ideas of action have been considered:

- Introduce a business unit responsible for activation that periodically contacts consumers via telephone, email, mobile marketing channels and social networks to inform about the existence of platform and its benefits
- Introduce a network of partners (NGOs, volunteering associations, other social initiatives, etc.) responsible for promoting the platform among producers and

Table 2 Feasibility analysis of business idea

Question	Solution
Which are the basic resources you need to start? Which is the interest/motivation?	Web portal/mobile app/partnership logistic network Quality of products/price/sometimes the lack of time
Who else can be attracted in this business with no difficulty? Did you identify all beneficiaries?	Small farmers/local dealers that compete with supermarkets/niche stores A: Families in urban areas with a certain level of education/some restaurants/some hotels/some private schools B: Small farmers
Which is the value added for beneficiaries?	A: Healthy food/traceability B: Better chances to sell at the correct price
How beneficiaries would react to this product?	Positive, but they need to be activated
Would beneficiaries involve in product co-creation?	Yes, they could propose recommendations for enhancements
What barriers do you envisage in implementing the business (any kind of barriers)?	Activation of both producers and consumers
Who would have the interest to block this business and why?	Current retailers in the markets/importers of poor quality products
From what sources it will be ensured business sustainability?	Monetization of vouchers
What risks would be in place?	Low quantity of high quality products/capacity of small farmers to join the network/capacity to activate in short time a critical mass of buyers and sellers
How large is the market?	10% of an urban community
What complementary businesses would be run?	Sell traditional products from vegetables, fruits, meet, milk
What new businesses would emerge and how large?	Customized handmade clothes sold through the system/ other handmade products/E-tailoring (work)shop
How much sophistication?	Eco agro-products
What about profitability level?	10%
What new businesses would occur from the results of this business?	Personalized providers of high end agro products/smart agriculture
What steps should be followed?	Partnerships with logistic networks/partnerships with providers of smart refrigerating boxes
Which would be the first steps?	Intuitive portal
Who will be involved before starting the business?	PR/network facilitators
What ideas do you have to overpass barriers?	Dedicated business units for activation/network partnerships with entities having social mission/ mechanisms for optimal price policies
What leverage effects do you see?	Internationalization and scaling up
What new opportunities could be born?	E-commerce for fast retail of promotional offers for big brands

working close with communities of producers to learn them how to use the platform and support them

- Reach the version 1.0 of the ecosystem by setting up an lead group of consumers to upload requests and activating a key group of producers
- Perform surveys to identify optimal prices for different products and promote them among producers, using also various incentives for encouraging some price policies

A Net-Present-Value (NPV) calculation and real option scenarios are necessary for designing the whole business model before business launching. Such details are not included in this paper.

The second case study relates with the business domain of education. Go-to-gemba approach for this domain reveals that an important segment of young generation disagrees with the traditional models of higher education in terms of their capacity to prepare them for practice. The same approach reveals that many children from villages and small towns whose families have low income do not follow a higher education path because of cost of living in the expensive university cities. A consortium of software outsourcing companies has seen a business opportunity in this social problem, as long as these companies face with a crisis of human resources. Mapping their business portfolio with the set of nine inventive principles, and having in mind the social problems SP1 “lack of fast, practice-oriented and free training for a well-paid job” and SP2 “low accessibility to higher education of children from low income families living in rural areas and small towns”, the result from Table 3 occurs, where P1 means “high-end software outsourcing services”, P2 means “software testing and QA”, and P3 means “customer care call centers”.

AI1-P1:P3 suggests the opportunity for setting up a private IT Academy. AI3-P1: P3 suggests the idea of accreditation of the study program with public agencies responsible with labor force (e.g. certificate for analyst programmer). AI4-P1:P3 leads to the idea of fast integration in real projects during studies. AI5-P1:P3 suggests project oriented curricula with graduation in 1.5 years. AI6-P1:P3 indicates direct link between graduation and employment. AI7-P1:P3 indicates provision of free accommodation during studies in social houses. AI8-P1:P3 suggests location of the IT Academy in a cozy small town with cheap living conditions. AI9-P1:P3 indicates collaboration with local administration to provide a free space for study as

Table 3 Mapping of current product portfolio and areas of intervention

	P1	P2	P3
AI1	SP1	SP1	SP1
AI2	–	–	–
AI3	SP1	SP1	SP1
AI4	SP1	SP1	SP1
AI5	SP1	SP1	SP1
AI6	SP2	SP2	SP2
AI7	SP2	SP2	SP2
AI8	SP2	SP2	SP2
AI9	SP2	SP2	SP2

a condition to bring the IT Academy in the town and then to open a local business unit.

From the set of ten disrupting vectors, the vector of “asymmetric construction” was found very useful in this case study. It led to the consolidation of the business vision that looks like: “A private IT Academy located in a small town with economic difficulties, with cheap living conditions, but positioned in a nice geographical area, which is primarily targeted to young intelligent people from low income families eager to follow a tertiary education with direct employment in the IT companies that are behind this IT Academy, companies that agree to set up the related operational units in that town and/or several small towns, but with expert management coming from the central unit (headquarter), with rotation of the management staff”. Return-on-Investment (ROI) is generated by returning the loan for studies once students engage in projects and afterwards, when they become employees. Other details on this case study are not provided in this paper.

5 Discussions

Successful businesses require, besides good products and/or services, viable business models. Thus, any business idea necessitates a deeper analysis from a financial point of view over its life-cycle in the context of a given business model. Even if the market potential exists, this does not guarantee the commercial success without the presence of an effective business model. For example, in the first case study, cost-effective solutions for market activation are crucial for commercial success. In the second case study, wide promotion campaigns in schools through face-to-face meetings of potential candidates and their parents are necessary.

Both case studies illustrated in this paper have financial sustainability. Numerical data are not provided here due to the fact both businesses are operational now and some information is subject to confidentiality agreement. This is also the reason not all details of the business models are revealed in the paper.

6 Conclusions

The main theoretical contribution of this paper is a methodology for systematic design of CSV-driven businesses. The thesis at the foundation of this methodology is that profitable businesses can be generated from social problems in any application domain if adequate products and related business models are in place. In this respect, go-to-gemba approach is essential for identifying social problems. Mapping proper inventive principles over the identified social problems in relation with the current business of a company significantly helps ideation of a CSV-driven business. The set of disrupting vectors is useful for clarifying the vision of the new business, whereas the subsequent set of questions are important for defining a viable business model in relation with the new business.

Two examples are provided in the paper for demonstrating the practical potential of the methodology. However, the methodology does not cover other essential pieces in relation with a new business, such as the entrepreneurial plan, the business plan and the financial plan. These pieces are necessary to proper understand how to approach the new business in a profitable and financially sustainable way.

Future researches will be focused on defining more systematic links between this methodology and the business model canvas.

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Mobile Biogas Station Design: The TRIZ Approach

Mariusz Ptak, Sebastian Koziołek, Damian Derlukiewicz, Marek Mysior, and Mateusz Słupiński

1 Introduction

Biogas is a mixture of combustible and non-combustible compounds resulting from the fermentation process. The most desirable component of biogas is methane (CH4). The first registered installation of municipal biogas were street lamps in Exeter, United Kingdom. Biogas from waste water treatment plants were used to power them. One of the first installation to obtaining biogas can is the Imhoffa tank used to mechanically obtain biogas form wastewater treatment. This design was used in Germany in the Ruhr area [1]. In 1923, the biogas is introduced to the municipal piping systems. In the following years, biogas was used in local cogeneration plants for production of heat and electricity. The attempts to clean biogas, compress in and further use it to drive motor vehicles were taken by the British army in 1930 [1]. Until World War II the development of tanks for biogas storage was progressively improved as well as the purification technology. The popularity of biogas also grew after the war—until 1955. Around that year, low oil price made this energy source competitive to biogas.

Another wave of development of biogas systems occurred in the beginning of XXI century. At that time, the trend and enforced law to use renewable energy subsidized energy production from biogas. As a result, 1500 biogas systems in Germany were created, mainly in Bavaria. Renewable energy law was adjusted in order to promote the formation of small biogas systems [1, 2].

The implementation of a system of distribution of biogas directly to factories, farms and special objects is a chance for more efficient use of this environmentally friendly fuel, where the biogas is used to produce electricity, heat and cooling. Any

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surplus of biogas can then be used to power motor vehicles (fleet or private) equipped with an installation dedicated for the supply of gaseous fuels. It implies, that biogas can become one of the best renewable energy sources and efficient alternative fuel used in transportation in the nearest future.

2 Problem Definition

Biogas may be in the near future, one of the best renewable energy sources and efficient alternative fuel not only in transport, but also in power stationary machinery, equipment and buildings without access to underground natural gas pipeline. This solution will enable the combustion of biogas and getting electricity, heat or mechanical only when it is in demand. Therefore, the fundamental problem is the refining, storage and distribution of biogas securely and economically justified.

Some issues of potential customers/suppliers which were identified by the authors through Design Thinking [3, 4] empathy map (Table 1).

Depending on the type of installation and the raw materials used there can be differences in quality and contamination of the biogas produced in industrial plants, which are a potential source of gas. For this reason, the planned drainage system, cleaning, conditioning and compression should be characterized by resistance to changing properties of biogas, so that the final product is purified biogas, characterized by a relatively constant property, which define it usage. The schematic presentation of a Mobile Biogas Station supplying energy to a local ZOO is depicted in Fig. 1.

3 System Operator

The location of the problem in the system can be presented by introducing Altshuller's diagram that contains nine separate cells, otherwise known as the system operator or nine-boxes [5–7]. Because no technical system exists in a vacuum, it is a schematic

Table 1 Identified issues connected with energy costs using empathy map

Customers	Suppliers
• energy costs • the high cost of natural gas (> 0.5 € per 1 m^3) • lack of alternative/cheaper source of energy • lack of pipeline biogas • inability to purchase biogas	• costs of the sale of electricity to the grid for 20% of the market price • 80% loss of thermal energy • location in non-urbanized area • decline in the value of green certificates • limited opportunities to sell thermal energy

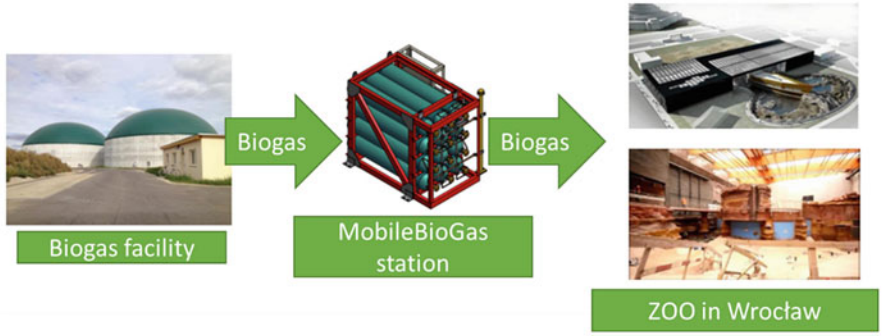

Fig. 1 Scheme of biogas distribution system using mobile station

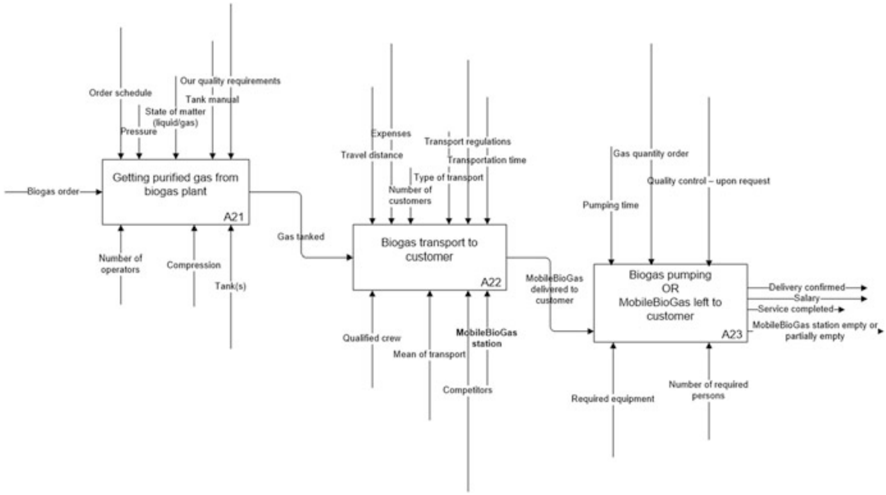

Fig. 2 Node A2-biogas distribution system

picture of the structure of the issues concerned. We can then look at the system more broadly and consider not only the phenomenon happening now (present), but also these happening/completed in the past and the future. In addition to the said horizontal structure on the stage of the system there is also under-and super-system.

If we consider the system as MobileBioGas (the Mobile Biogas Station), its supersystem may be a universal system of transportation, while the subsystem is to provide biogas. Analyzing the problem through TRIZ methodology one can see it on the background of the system operator grid, where the present is closely linked to what has already occurred or will occur within specified time. Chris Killer, from Bath University, writes: "creative people naturally think in the context of time and space" [8]. Therefore, we are encouraged to think in the framework of time and space [9, 10]. Figure 2 shows the system operator for the MobileBioGas and for distribution with the use of MobileBioGas (Tables 2 and 3).

Table 2 System operator for Mobile Biogas Station design

Supersystem	Farms, municipal waste management plants, waste water treatment plants	Universal transport system (e.g. ISO: rail, road, air, water)	The energy system of buildings, machinery and equipment
System	Biogas plant	MobileBioGas	Generator boiler/chiller/ internal combustion engine
Subsystem	Waste	Biogas	Energy
	Yesterday	Today	Tomorrow

Table 3 System operator for distribution system of biogas

Supersystem	Energy production in plants	Delivery of biogas to the recipients, exchange and leveling	Waste collection and delivery of biogas (balancing)
System	Distribution only in biogas plants	Distribution using MobileBioGas	A mobile reactor
Subsystem	Purified biogas quality NG	Partially purified biogas	Waste
	2000	2015	2030

4 Functional Modeling Using IDEF-0

Graphical representation of the MoblieBioGas system, using IDEF0 method, starts by creating a model of three ICOM cubes [5, 11]. The effect of mapping method by IDEF0 is a series of hierarchical structure diagrams, and each scheme comprises a plurality of cubes, i.e. the operation, action, coupled together by means of arrows. The out-arrows of one cube are also in-arrows for the next cube. Due to limitation of the paper volume only a part of the IDEF0 model is presented. Thus, in accordance with the IDEF0 rules, Biogas distribution system, is shown in Fig. 2. The cubes representing the process and arrow input (left), output (right), control (up) and mechanisms (down).

The whole system consists of the following nodes:

- Node A1. Biogas production;
- Node A2. Distribution of biogas
- Node A3. The exploitation of biogas.

The IDEF0 method allowed thoroughly and accurately reflect the part of the distribution of biogas. Mapping the biogas distribution system in IDEF0 technique brought many benefits. Primarily, the IDEF0 model allowed the authors to document, with appropriate level of detail, the basic stages of distribution of biogas from its production until operation. Sequentially, the process provided information on how individual technological operations and logistics depend on each other, and what is the order of the operations. In summary, the main advantage of the IDEF0 method is to capture, in a graphical way, the biogas distribution process, which allowed the authors to immerse into the process and answer some basic, yet important questions.

5 Mobile Biogas Station Design

On the basis of developed concepts and system of construction, a geometric model of the Mobile Biogas Station was developed. The model was constructed using professional CAD system and further stress-optimized through finite element method [12–17]. The geometrical models of the Mobile Biogas Station are shown in Fig. 3.

Designed Mobile Gas Storage Unit is capable of multimodal transport of up to 7400 nm^3 of unpurified biogas having 54.7% of Methane (CH_4). Total weight of transported gas having such content of methane is 8300 kg. The gas container consists of 68 type 3 CNG Cylinders that are suitable for transport of Biogas, each having 220 l of water volume. This in total gives 14,960 l of water volume, excluding the volume in pipes and valves. Biogas is stored under pressure of 200 bar, having capacity to be filled by fast filling process in less than 2 h. All necessary connections and ports are provided in the design. External dimensions of the container comprises to the international standards for containers. The design can be divided into three groups of assembly. First one is the frame of the container that supports cylinders and its piping. The second group is the set of gas transport modules, each of capacity less than 3000 l water volume that contains gas in transport. Last group contains covers and service door, which protects the piping and gas during transport.

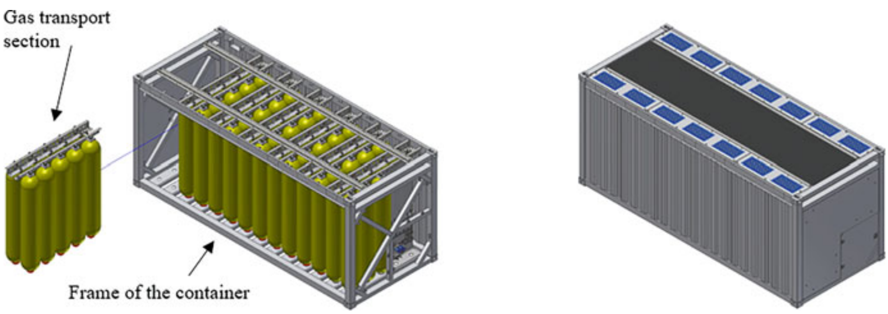

Fig. 3 Geometrical models of Mobile Biogas Station. Stations without covers (left); station ready for transport (right)

Table 4 Technical specification of the Mobile Biogas Station

Designation of the container	1CC
Container length	20 ft. (6058 mm)
Container width	8 ft. 6 in (2591 mm)
Container height	8 ft. (2438 mm)
No. of cylinders	68
Water volume of one cylinder	220 l
Working pressure	200 bar
Filling pressure	260 bar (FFP compliance)
Diameter and length of cylinders	394 mm × 2360 mm
Mass of one cylinder	75 kg
Cylinder boss	Double neck, vertical mount with thread, SAE ports 1.125–12 UNF
Total water volume	14,960 l
Biogas capacity	7400 nm^3
Mass of transported biogas	8300 kg

The gas container is characterized by vertical placement of cylinders, which is done because of safety issues [18, 19] and easier assembly of the construction. The summary of technical specification of the Mobile Biogas Station is shown in Table 4.

As a part of design process, the FEA (finite element analysis) was conducted. According to the standards ISO 1496-3:1995 [20, 21] and ADR [22] there are in total 12 static loading conditions that have to be taken into consideration in design of the mobile gas storage unit. Important situations are stacking of containers, restraint, rigidity test as well as rapid braking. Each prototype of the mobile gas transport container has to be tested dynamically for an event of a crash [22]. The results of Finite Elements Analysis of the Mobile Biogas Station in response to the top lift test is shown in Fig. 4.

The FEA model was prepared such that the cylinders were represented as a rigid beams supported at each end, having a point mass equal to the mass of the cylinder with biogas inside in the middle of the length of the cylinder. Loads and constraints were applied according to the ISO 1496-3:1995 standard. After FEA it was necessary to strengthen the front and rear side of the container because of the rigidity test. The geometry of the mobile biogas station before and after optimization using FEA is shown in Fig. 5.

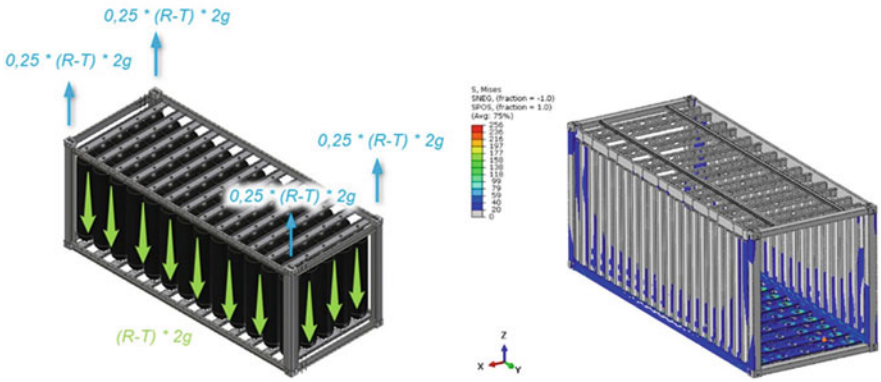

Fig. 4 Finite elements analysis of the gas container: boundary conditions (left); HMH stress [MPa] (right). Total mass of the container with gas, T-mass of the container without gas

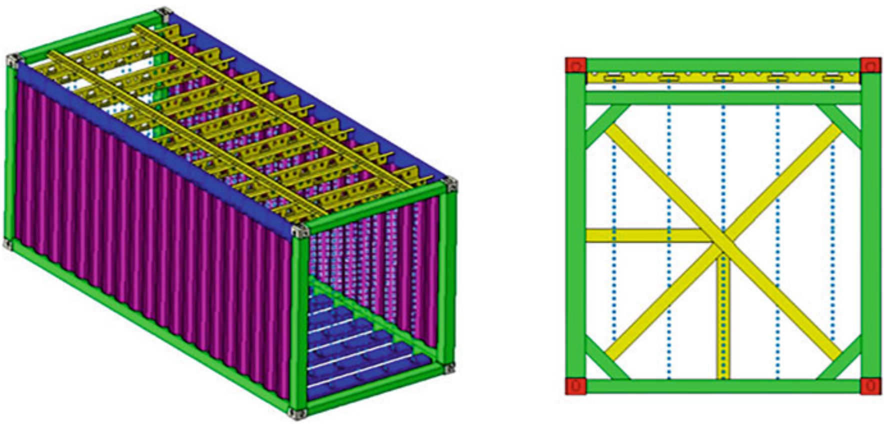

Fig. 5 Geometrical models of Mobile Biogas Station. Before FEA analysis (left) vs. optimized container face (right)

6 Conclusions

The TRIZ-aided designed MobileBioGas station allows for economically justified transport of biogas using many modes of transport like road or rail transport. Due to the form of the ISO Container it is easy to manipulate the station with many devices that are normally used for transport of the containers. It is especially important from the point of view of the supersystem, because it is adopted to the current state of the art in bulk transport. Having the station designed, it is possible to supply end users with biogas in the amount they need by selecting a proper type of trailer. It is also possible to transport one container having 7400 nm^3 on a truck itself or to use container trailer to take two such containers, so more than 14,000 nm^3 of biogas.

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Cause-Effect Chains Analysis Using Boolean Algebra

Jerzy Chrząszcz and Piotr Salata

1 Introduction

Cause analysis has been used for decades in numerous areas of business and technology, with various goals aimed and with different approaches taken. Identification of causes of past / actual events - like non-conformity in a management system or fault in a technical system - allows for planning adequate corrective actions. For future / anticipated events, in turn, such analysis may support risk estimations or identification of weaknesses of the system. In all cases, however, the common objective is to proceed the analysis to the level that allows for gaining intended benefits. Therefore proper identification of the *right cause* is crucial for the successful outcome of the cause analysis.

Cause-Effect Chains Analysis (CECA) is a TRIZ tool for identifying inventive problems [1], hence finding *right cause* should result in formulating *right problem* to be solved. Among several root cause analysis methods developed for particular applications, the Fault Tree Analysis (FTA) [2, 3] and Why-Why (also known as Five Whys) are often referred to in TRIZ literature.

They are recalled for comparison with CECA [4, 5] or for exploration within the framework of other TRIZ tools [6]. In either case the researchers must face inconsistent terminology: TRIZ uses generic terms *disadvantage* or *undesired effect*, while in other methods we have *fault*, *failure*, *undesired event* and *unintended event*, not to mention *error* and *bug* in IT industry. Moreover, the term *failure* is reserved for root causes in FTA and the same word is used elsewhere as opposition to successful system operation, what obviously corresponds to the opposite end of the cause-effect chain than root cause.

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In spite of this ambiguity, there are significant similarities among said approaches, especially between CECA and FTA. Firstly, each of the methods involves iterative building of a system model for the purpose of supporting decisions regarding changes in that system. Secondly, both methods use directed graphs with edges denoting causality flow and logical operators indicating correlation between events that contribute to given effect. Finally, both CECA and FTA are being researched for improving or automating model creation by applying rules [7] or formal criteria [8] or solution patterns [5, 6].

CECA model is created by determining cause-effect chains starting from initial disadvantage (surface problem) and determining its subsequent causes until reaching root causes that represent natural, legal or business constraints that cannot be eliminated. If at any stage the effect results from more than one cause, then appropriate relation is modelled with operators (gates) combining the inputs with logical alternative (OR) or conjunction (AND). The process stops when all target disadvantages (initial disadvantages within the scope of project) are analysed and all key disadvantages are revealed.

Resulting CECA model reflects the influence of underlying disadvantages on the target disadvantages in two aspects: by documenting the nature of causality for all cause-effect pairs (how the system operation is affected) and by documenting the structure of causality (how the causes propagate among nodes). The former is tightly related to application area of the analysed technical system, hence specific knowledge is required to use this layer of information. The latter, however, is application-independent, as it comprises just boxes, edges and gates. Such diagram resembles scheme of an electronic circuit built with connected gates.

The following sections of the paper demonstrate how methods used for synthesizing and testing of logical circuits may be applied for analysing CECA model. The use of these techniques leads to models which have several advantages:

- they are simpler and more compact;
- they reveal the essence of influence of root causes on target disadvantages;
- they can answer structural questions in more convenient way than original CECA models.

2 Building Logical Model

Digital electronic circuits use defined signal levels, which are properly distinguished on inputs and properly generated on outputs. The simplest and most widespread version of this concept is to use only two levels that correspond to *true* and *false* in Boolean algebra and are denoted as 1 and 0, respectively (binary logic). Logical gate has one or more inputs and one output, which depends solely on the state(s) of input(s) and the Boolean function is determined by the type of the gate:

- AND gate implements logical conjunction i.e. it outputs 1 if and only if all its inputs are 1s. Otherwise it outputs 0.
- OR gate implements logical alternative (disjunction) i.e. it outputs 0 if and only if all its inputs are 0s. Otherwise it outputs 1.

In some materials regarding CECA the choice of OR gate is recommended *if input causes are independent* and AND gate is recommended *if removal of one contributing disadvantage automatically removes the others*. It should be noted, however, that logical relation have nothing to do with dependence (or independence) between source causes, as both ORs and ANDs may have inputs affected (or not) by a common cause. Proper identification of independence between causes is crucial for probability calculations performed within FTA, but it is not explicitly addressed in CECA.

Independence can be used in cause-effect analysis in a different context: properly stated rules are that OR gate should be used when the *influence* of one input cause on the effect is independent from that of another input cause (regardless of the level of dependency of the causes on each other). Similarly, AND gate should be used when elimination of one cause makes *influence* of other causes insignificant.

Besides, a few erratic reasoning patterns have been identified [9], that result in incorrect selection of AND / OR logical gates for modelling interrelations of causes within CECA process, when *positive* and *negative* description is used (i.e. both existence and elimination of disadvantages are considered). This will be discussed in Sect. 5.

CECA model may be converted into a diagram of logical circuit of equivalent structure using the following rules:

- gates remain as they are;
- boxes become *repeaters* with outputs described by binary variables: 1 denotes presence / activity and 0 denotes absence / inactivity of a particular disadvantage;
- directed edges become connections from outputs to inputs, i.e. an output controls the signal level, which is then sensed by input(s).

An example of CECA model and equivalent logical model is shown in Fig. 1, with key disadvantages *k1-k6* and target disadvantages *t1-t4*. Arrows and labels of the intermediate causes have been omitted for clarity.

3 Transforming Logical Model

For functional completeness Boolean algebra requires negation, which is unary operator implemented as single-input NOT gate (inverter) that outputs 1 if its input is 0 and vice versa. Although CECA models do not show explicit NOT gates, they may possibly contain descriptions of complementary states, e.g. *pressure is less than P*

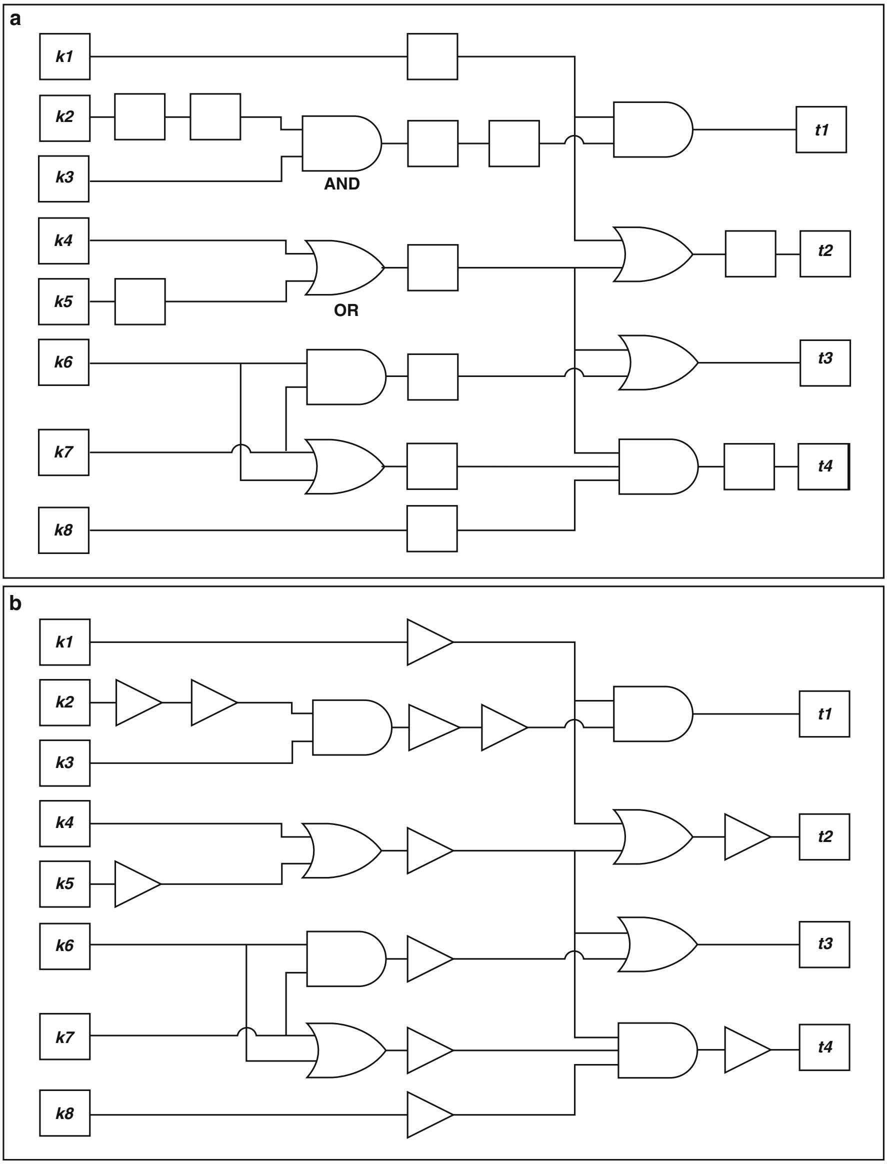

Fig. 1 Sample CECA diagram (a) and the result of its transformation into equivalent logical model (b)

and *pressure is equal to or greater than P*. In such a case, opposite conditions may be derived from a shared input using repeater and inverter. Therefore it seems advisable to identify complementing conditions and adjust logical model after conversion in order to properly reflect mutual exclusivity of the variants.

By definition, repeater propagates signal without change, so that output of a chain of repeaters simply follows its input. That is why arbitrary number of adjacent repeaters may be replaced by the first one (as far as logical function is considered).

Furthermore, if a repeater's input is controlled by a gate, its output always follows the output of the gate and such repeater may be eliminated as well. This transformation compacts linear sub-chains of the model and preserves its branching structure. After aggressive compaction the model would only contain input variables (for key disadvantages), output variables (for target disadvantages) and a network of interconnected gates between them. Figure 2 shows the same model after identification of two pairs of complementary conditions *(k4-k3, k6-k7)* and compacting sequences to single repeaters.

In addition to graphical diagram with gates, logical circuit may be alternatively represented by expressions consisting of identifiers of binary variables and operators indicating logical operations on these variables. Prefix notation (used in Microsoft Excel expressions, for instance) is convenient for automatic parsing and symbolic processing of expressions, but infix notation is more appropriate when human readability is important. Consider for instance two descriptions of a simple function with four inputs $y = f(a, b, c, d)$:

$$y = OR(AND(a, b, c), AND(a, b, d), AND(b, c, NOT(d)))$$
$$y = abc + abd + bcd'$$

The second formula is much easier to read because of its similarity to arithmetic expression, with concatenation denoting AND (as for multiplication), plus sign for OR (as for addition) and apostrophe indicating negation of a variable. Expressions describing compacted logical model shown in Fig. 2b are given below.

$$t1 = k1k2k4^{'}$$
$$t2 = k1 + k4 + k5$$
$$t3 = k4 + 45 + k6k6^{'}$$
$$t4 = (k4 + k5)\left(k6 + k6^{'}\right)k8$$

It has been proven that arbitrary Boolean function may be expressed in several canonical forms and the most popular are Canonical Disjunctive Normal Form (CDNF), structured as a Sum of Products (SoP) and Canonical Conjunctive Normal Form (CCNF), structured as a Product of Sums (PoS). Both canonical forms use all input variables in each subexpression, what may (and often does) result in redundant representation. Therefore logical functions are usually described as minimal PoS / SoP expression.

Elimination of a target disadvantage is modelled by respective output variable evaluating to 0. In order to achieve this, SoP representation (OR-ed ANDs) requires

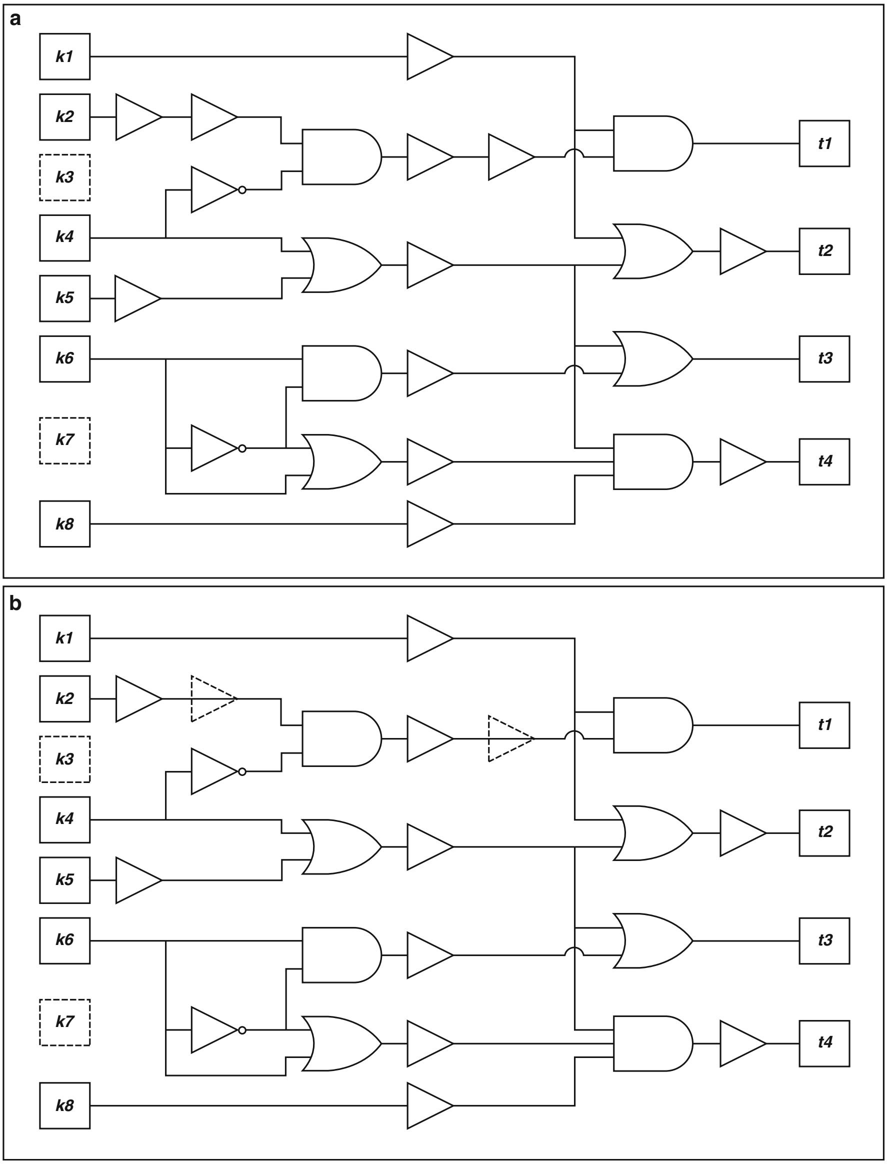

Fig. 2 Logical model from Fig. 1 with additional inverters for complementary conditions k4-k3, k6-k7 (a) and after compacting chains of repeaters (b)

that input variables should be manipulated is such a way, that ALL outputs of AND gates evaluate to 0s. From this perspective PoS representation (AND-ed ORs) appears more appealing, as it requires ANY of the OR outputs to evaluate to 0. Unfortunately, in order to maintain regular two-level structure both SoP and

PoS use input variables taken directly and with negation, what complicates interpretation. This will be discussed in Sect. 5.

Important stage in the synthesis of logical circuit is minimization, aimed at finding the *cheapest* implementation, i.e. minimal set of gates providing required logical functions between inputs and outputs. If original CECA model has T target disadvantages and K key disadvantages, then equivalent logical model may be minimized as a set of Boolean function with K inputs and T outputs.

Minimization may result in elimination of some gates or even whole branches, especially if inverters are present in the structure. Let us point, that complementary signals always have opposite values so that AND gate would always generate 0 from such signals, regardless of the number and states of other inputs, and OR gate with arbitrary number of inputs would generate constant 1 in such conditions. And even if complementary signals go through different gates, they increase chances for reduction of complexity.

For instance: $y = abc + abc'$ is equivalent to $y = ab$. Indeed, if the output is same for c and c', then it is actually independent of this input. The final results of compaction and minimization are shown in Fig. 3.

The following expressions describe minimized logical functions depicted in Fig. 3b in minimal SoP notation:

$$t1 = k1k2k4'$$

$$t2 = k1 + k4 + k5$$

$$t3 = k4 + k5$$

$$t4 = (k4 + k5)k8 = k4k8 + k5k8$$

Formal transformation of logical model based on above mentioned techniques has several limitations and cannot be applied to some structures. Particularly, it cannot be used when there is a loop (*vicious circle*) in the CECA model. Therefore, models containing such structures should be at first transformed using another set of rules. They allow for removal of loops from the model so that logical circuit synthesis methods can be applied. This will be discussed in Sect. 5.

4 Exploring Logical Model

Proper minimization should remove all unnecessary gates from the logical model. Consequently, the expressions describing minimized model should reflect the core interrelations between inputs and outputs. Sample questions to the model are given below, together with proposed approach for obtaining the answers.

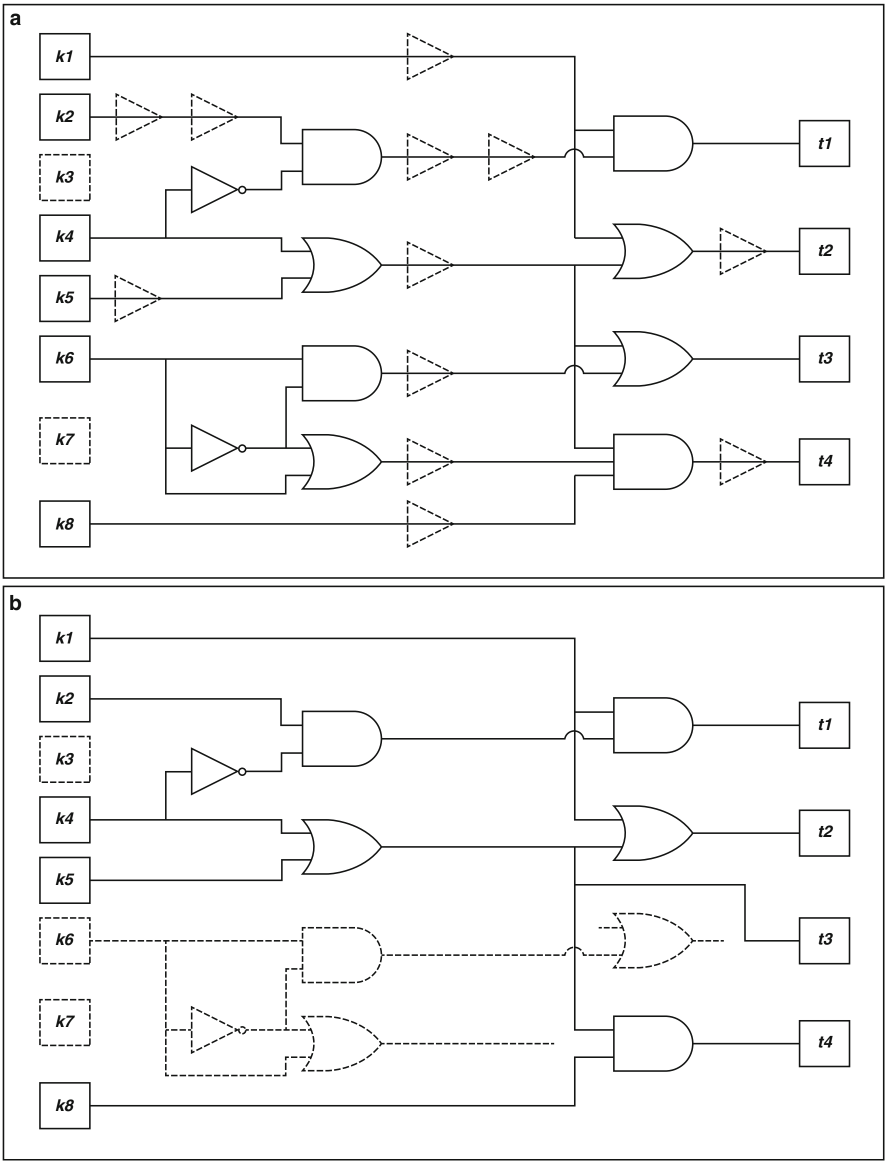

Fig. 3 Logical model from Fig. 2 after aggressive compaction (a) and after minimization (b)

Which inputs influence particular output? The answer is the list of input variables in the minimized expression describing respective output. For the example model discussed here the answers are as follows:

$$t1 : (k1, k2, k4)$$
$$t2 : (k1, k4, k5)$$
$$t3 : (k4, k5)$$
$$t4 : (k4, k5, k8)$$

Which inputs have the greatest influence on outputs? This matter might be addressed in several ways, depending on particular meaning of *influence*. The basic solution is to count the outputs affected by particular input and then sort the values in decreasing order. For the example model this would result in the following sequence:

$$1 : k4\ (4)$$
$$2 : k5\ (3)$$
$$3 : k1\ (2)$$
$$4 : k2, k8\ (1)$$

One may also use weighted scores instead of raw counts, taking, for instance, fractional values *1/n* with denominator representing total number of input variables in respective expression. For the example model the scores are:

$$1 : k4\ \left(\frac{1}{3} + \frac{1}{3} + \frac{1}{2} + \frac{1}{3}\right)$$
$$2 : k5\ \left(\frac{1}{3} + \frac{1}{2} + \frac{1}{3}\right)$$
$$3 : k1\ \left(\frac{1}{3} + \frac{1}{3}\right)$$
$$4 : k2, k8\ \left(\frac{1}{3}\right)$$

What minimal set of inputs must be acted upon in order to deactivate particular output? This question comes closer to the original goal of CECA, i.e. supporting decisions on changes. To find the answer, one may identify all possible combinations of input variables resulting in 0 at respective output, what is actually equivalent to finding negation of the original function defined for this output. Such complementary function after minimizing to SoP form will be expressed as OR-ed ANDs, so that AND with the least number of inputs will determine the answer. For the example model this would be:

$$t1' = k1' + k2' + k4$$
$$t2' = k1'k4'k5'$$
$$t3' = k4'k5'$$
$$t4' = k4'k5' + k8'$$

What minimal set of inputs must be acted upon in order to deactivate all the outputs? One way of identifying inputs that may deactivate all outputs is to build a list of the input variables of the least-cost ANDs in complementary functions of all outputs (as described above). This is straightforward, however combined local minima does not have to be global minimum and to determine optimal solution one should analyse coincidence of conditions required for deactivation of each output alone, what is equivalent to AND-ing expressions of complementary functions.

For the example model legitimate choices within the first (heuristic) approach would be $k2'$ for $t1$ and $k8'$ for $t4$, what leads to suboptimal solution:

$$(k2')(k1'k4'k5')(k4'k5')(k8') = k1'k2'k4'k5'k8'$$

while for the second (analytical) approach transformation of the product $t1't2't3't4'$ gives the minimal solution:

$$(k1' + k2' + k4)(k1'k4'k5')(k4'k5')(k4'k5' + k8') = k1'k4'k5'$$

Indeed, as can be seen in Fig. 3, removing key disadvantages $k1$, $k4$ and $k5$ is sufficient to eliminate all target disadvantages, so those root causes might be called *basic root causes*.

5 Limitations of Use

Model transformations, minimization and exploration described in the preceding sections have been focused on its structure and logical interrelations. This perspective implies several consequences, which are discussed below as limitations of the proposed approach.

Root causes are beyond the scope of project, as a rule, and so they cannot be eliminated. This rises question if they should be used as input variables and for what purposes. The answer is positive if one is interested in evaluating the impact of e.g. project constraints on particular target disadvantages. Although the root causes must not be literally *eliminated*, it might be possible to avoid them by introducing changes in the system or its super-system. It is also possible to feed the logical model with other set of input variables, chosen adequately to considered intervention or aspect (e.g. materials, transmission, etc.).

Negated inputs may appear in the model to represent complementary states (as explained in Sect. 3) or as a result of transforming the original network to standard SoP / PoS notation. The former seems beneficial for denoting variants which are mutually exclusive, but there is probably little chance to use this technique if only the root causes are used as inputs. And when it comes to normalized and minimized expressions, negated inputs might be difficult for interpretation because they should be manipulated oppositely than direct inputs. For instance the formula $y = a + b'$ requires disadvantage a to be eliminated and disadvantage b - surprisingly - to be intact in order to get rid of the disadvantage y.

This ambiguity may be addressed by using Algebraic Normal Form (ANF) also known as Zhegalkin normal form, which does not use negation. ANF notation relays on Exclusive OR operation (XOR), which is similar to ordinary OR (sometimes called inclusive OR to make the difference), except that it outputs 0 for all 0s as well as for all 1s. Simply put, XOR gate outputs 1 for different values on inputs and 0 for equal values on all inputs. ANF usually appears in literature on digital circuit testing as the introduction for Boolean difference [10], which is used for determining *sensitivity* of a logical function to a change of particular argument.

Boolean difference is calculated as XOR of a function expression with given input set to 0 and the same expression with this input set to 1, e.g.:

$$\frac{dy}{da} = y(0, b, c, \ldots) \oplus y(1, b, c, \ldots)$$

If the result evaluates to constant 0, the output does not depend on this input at all, and constant 1 means that changes of this input always (unconditionally) propagate to the output. Finally, if the result evaluates to a logical expression, then the output is *conditionally sensitive* on particular input, with the condition explicitly indicated by the expression, for example:

$$y = abc + acd$$

$$\frac{dy}{da} = 0 \oplus (bc + cd) = bc + cd$$

This implies that if $c = 0$, then the output is not sensitive on a. In other words, changing a has no effect in such condition. Hence, Boolean difference allows for systematic evaluation of sensitivity of model outputs (target disadvantages) on changes of any node in the logical network.

Logical expressions may be incorrect. It seems that logical models build form CECA diagrams are twofold exposed on potential errors. Firstly, they directly suffer from incorrect use of logical operators, as pointed in [9] and later those errors may double when complementary functions are evaluated and analysed (as described in Sect. 4).

Incorrect AND / OR selection may result from improper understanding of the structure or operation of the analysed system or its super-system as well as from confusing relation between causes of the disadvantages and relation between respective remedies, as $(a + b)' = a'b'$ and $(ab)' = a' + b'$. Supposedly, the latter type of errors might be easily avoided by observing simple rules derived directly from description of logical conjunction and alternative given in Sect. 1:

- if ALL input causes must appear jointly to trigger the output disadvantage, the relation should be modelled with AND gate (and then elimination of ANY of the input causes is sufficient to get rid of this disadvantage);
- if ANY of the input causes is sufficient alone to trigger the output disadvantage, the relation should be modelled with OR gate (and then ALL input causes must be eliminated to get rid of this disadvantage).

Diagrams with loops require structural transformation. Digital design techniques mentioned above are dedicated for combinatorial logical, i.e. circuits which outputs depend solely of current states of inputs. Each loop in the diagram constitutes a feedback that may transform combinatorial circuit into sequential one, which outputs also depend on history of previous input states. In order to avoid such feedbacks, the loops should be converted into different structures that are suitable for further compaction and minimization.

If we want to retain elements of the loop on a diagram, one of the following solutions can be chosen:

1. Removal of one connection that converts a loop into linear structure. If no additional hints are available, it seems advisable to cut the connection which is next to the node propagating causality outside the loop, as in Fig. 4b.
2. Transformation to an AND gate, as shown in Fig. 4c. Justification for this approach is that removal of any cause in the loop deactivates its output (so that all contributing causes must be active to give the effect), what is equivalent to logical conjunction.

When we do not need to keep the elements of a loop in a model, they can be reduced by substituting the whole loop with one *general* cause, as in Fig. 4d.

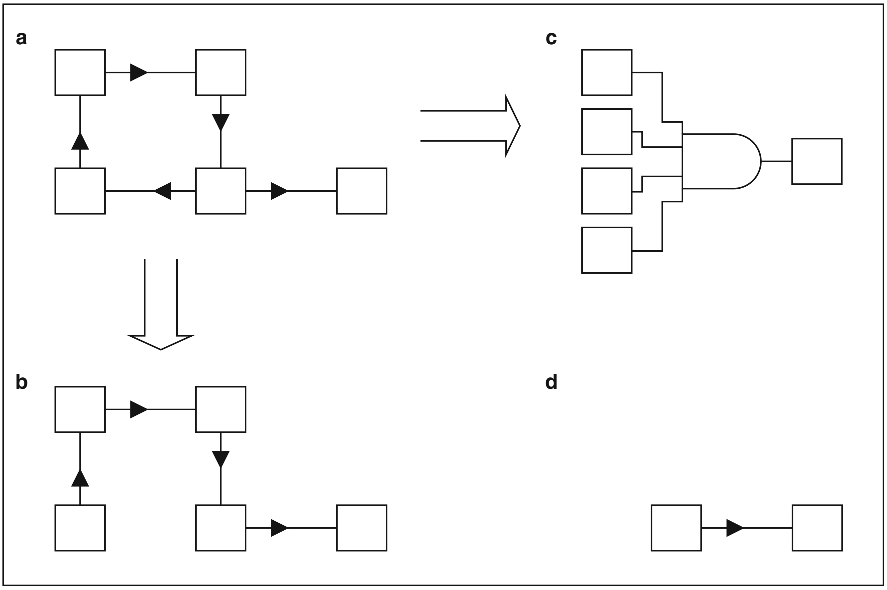

Fig. 4 Example loop in a diagram (a), recommended linearization (b), proposed conversion into AND condition (c) and reduction (d)

6 Real-World Example

The model depicted above was created specifically to demonstrate described operations. In order to verify the method in practice, we applied it in an ongoing project targeted at developing Unmanned Aerial Vehicle (UAV) system for delivering blood and other urgent medical shipments. As discussion of the full CECA diagram is beyond the scope of this paper, we only present some findings regarding selected target disadvantages: *insufficient flight distance*, *insufficient payload*, *excessive impact at emergency landing* and *excessive noise during flight*.

Analysis revealed 10 key disadvantages and 14 intermediate disadvantages. Some of them appeared to be complementary conditions, but eventually we could not use any NOT gates. For instance: *insufficient propeller rotation speed* must not be regarded negation of *excessive propeller rotation speed*. This is because neither condition covers the *appropriate* speed and because rotation speed being *insufficient* in terms of required lift force might be *excessive* with respect to acceptable noise level. Indeed, proper use of negation requires conditions that are actual logical complements of each other: they do not overlap and combine together to whole space of possible values.

Input ranking indicated *inefficient energy management, excessive vehicle weight* and *insufficient efficiency of energy source* to have the greatest influence on outputs, while *insufficient energy harvesting* disappeared in minimization.

Although usability of the method for transformation and exploration of real cause-effect model was confirmed, we did not encounter any exceptional results during the analysis.

7 Conclusions and Further Work

Proposed approach comprises CECA diagram conversion, identification of complementary conditions, transformation of loops, compaction of linear sub-chains and minimization of logical functions. The outcome of the processing is a simplified logical network preserving structure and logical relations between inputs and outputs of the original CECA model.

This representation, especially in the form of symbolic expressions, may be used for manual or automated analysis of some properties of the model, that are important for evaluating and comparing candidate changes in the system. This appears easier and more systematic way than investigating paths in CECA diagram, particularly for large or complex graphs.

After analysing drawbacks and limitations of the process, the following ideas appear the most interesting:

- modelling of complementary variants with NOT gates;
- transforming or removing loops from the model;
- using Boolean differences for determining sensitivity;

- extracting basic root causes from minimized functions;
- evaluating changes with complementary functions.

As mentioned in the beginning, FTA seems similar to CECA in several aspects. Transformation into logical model discloses additional similarity, since minimized logical expressions are just like Minimum Cut Sets (minimal combinations of events jointly causing particular top-level faults), constituting results of qualitative FTA. Quantitative FTA, in turn, aims at computing probability of faults, which is not a primary concern in CECA. Instead, it would be useful to evaluate considered change scenarios using business parameters (e.g. estimated cost or workload) rather than analytical measures. Perhaps there are still more inspirations for CECA in FTA, for instance additional gate type for modelling specific sequence of events.

These topics open several directions for researching the use of Boolean algebra for analysing CECA models.

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A Praxiological Model of Creative Actions in the Field of Mechanical Engineering

Maksymilian Smolnik

1 Introduction

Praxiology could be considered as the science of actions effectiveness [1]. It has been developed by, among others, Tadeusz Kotarbinski. Praxiology offers an actions modelling method which may be used during designing, evaluating or modernising the systems where different actions are performed in order to achieve the desired goals. Jozef Konieczny presented a concept of the application of the praxiological models to the technical systems operation and maintenance processes [2–4] as well as the other types of actions [4, 5].

An action realisation process is a process of conscious and intentional functioning with the ability to make decisions (cf. [5]).

The system of artefacts which become human artificial environment was called the technosphere [6] by Janusz Dietrych. There are at least four basic processes which refer to the technosphere and are the subjects of interest of technology. They are designing, manufacturing, using and maintaining, and finally disposing.

These processes may be considered as actions, therefore they could be modelled with the use of praxiological models. What is more, the realisation of these actions often affects the safety of people, may result in a huge social costs and requires great amounts of financial resources so it should be carefully planned, therefore a need for its proper designing occurs (cf. designing objects and processes [7] as well as the problem of responsibility in technology development [8, 9] and the most important problems of design methodology [10]).

The praxiological model of creative actions (cf. [11, 12]), presented in the article, allows the designer to indicate the relations of support between different actions within such a design process.

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2 The Basic Praxiological Model and the Actions Referring to the Technosphere

A general (and probably the simplest) praxiological model used for actions modelling is called a praxiological chain. The chain consists of three elements, which are as follows: the subject, the tool and the object. All of the mentioned elements are essential for realisation of the analysed action. The praxiological chain is described using the formula 1, where [2, 5]:

- C represents the chain
- x represents the subject
- y represents the tool
- z represents the object.

The complete graphical model of the chain is shown in the Fig. 1.

$$C = \langle x, y, z \rangle \tag{1}$$

The elements of the chain may be characterised using the formulas 2, 3 and 4, where [2]:

- P represents the set of people
- G represents the set of all of the elements which may be introduced as elements of the praxiological chain.

Therefore the set G consists of:

- the set of people P
- the set of technical devices and units consisting of technical devices T
- the set of remaining elements and units consisting of remaining elements R (these are the elements which are essential for the realisation of an action but are neither people nor technical devices).

$$(\langle x, y, z \rangle \in C) \rightarrow (x \in P) \tag{2}$$

$$(\langle x, y, z \rangle \in C) \rightarrow (y \in G) \tag{3}$$

$$(\langle x, y, z \rangle \in C) \rightarrow (z \in G) \tag{4}$$

A number of praxiological chains may be linked with each other in order to present the fact of one action being supported by another action. Such a support

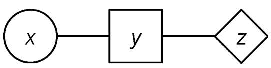

Fig. 1 A praxiological chain [2, 5]

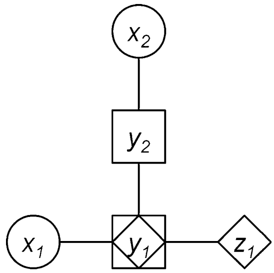

Fig. 2 A praxiological model of the actions associated with the usage and maintenance of a machine [2–4] operating within a manufacturing process; x_1—machinist miller, y_1—milling machine, z_1—workpiece, x_2—maintenance staff, y_2—maintenance tools and materials

allows one to increase the effectiveness of achieving the desired goal during the realisation of an action or even enables one to perform the action at all.

An exemplary, simple praxiological model of some selected actions within a manufacturing process, incorporating the typical model of machine's operation and maintenance [2–4], is presented in the Fig. 2.

The chain representing the action connected with using the milling machine $<x_1,y_1,z_1>$is supported by the chain representing the action connected with maintaining the machine $<x_2,y_2,z_2>$. The supportive relation between these two chains results in the presence of the machine (the y_1 element) in both of the chains. It is described with the use of the Eq. 5.

$$y_1 = z_2 \tag{5}$$

The presented models should be used for modelling more complex sets of actions by linking a number of chains with each other, and consequently a sequence of chains, a praxiological dendrite or a network may be built (cf. [5]).

Some features of the praxiological models compared with the other selected models of processes and functions were presented in the paper [13], and the possibilities of applying these models for modelling the actions organised by an algorithm were discussed in the paper [14].

3 A Praxiological Model of Creative Actions

The steering of realisation of an action is (at least partly) connected with its prior planning, which could be considered as designing of this action (and the process of its realisation; cf. [7]).

If designing actions is an action itself, it may be analysed or synthesised with the use of praxiological models. It could be modelled this way even when realisation of the action is a design process as well.

Assuming that designing inevitably includes some aspects of creativity (cf. [15]), a praxiological model of a design process could be considered as a model of creative actions, especially in the field of mechanical engineering.

The proposed model is presented in the Fig. 3. All of the praxiological chains included in the model are shown in the Figs. 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15.

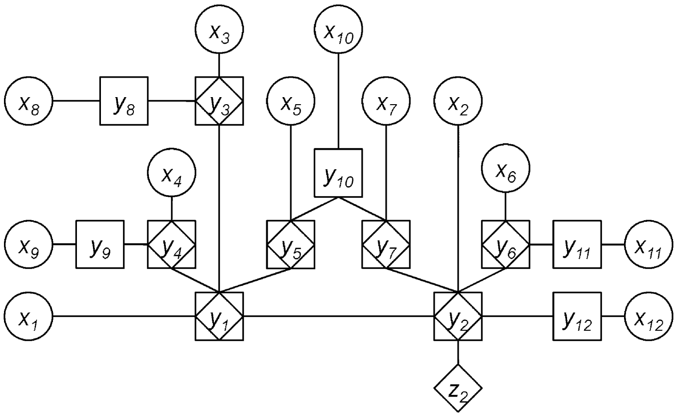

Fig. 3 A general praxiological model of creative actions in the field of mechanical engineering; x_1, x_2,...,x_7—designer, x_8—customer, x_9—methodologist, x_{10}—teacher, x_{11}—standards committee, x_{12}—information (data) management tools manufacturer, y_1—creation, y_2—information (data) management tools, y_3—design problem (task), y_4—design methods, y_5—design knowledge and skills, y_6—recording (drawing) methods, y_7—recording (drawing) knowledge and skills, y_8—need, y_9—(design) methodology, y_{10}—communiques and tasks (exercises), y_{11}—standards, y_{12}—production means, z_2—communique

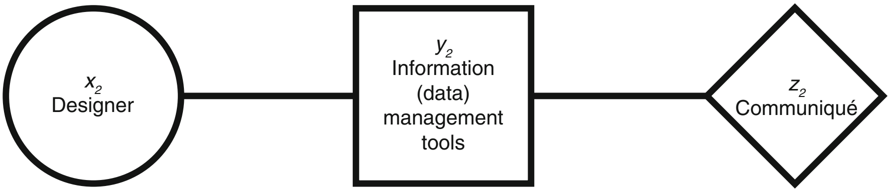

Fig. 4 <x_2,y_2,z_2> chain (C2)

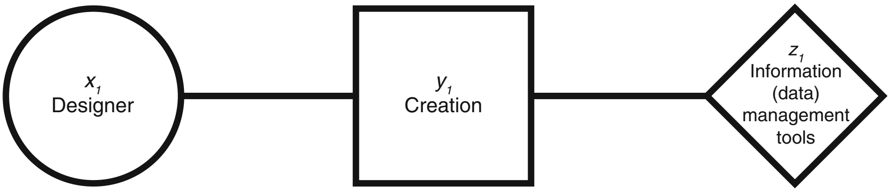

Fig. 5 <x_1,y_1,z_1> chain (C_1)

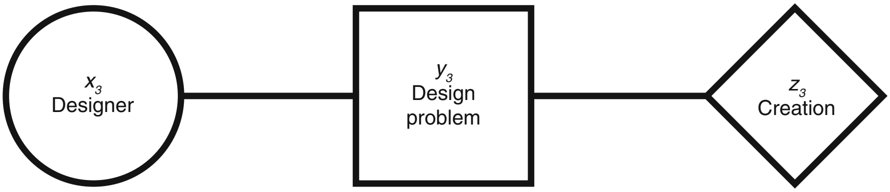

Fig. 6 $<x_3,y_3,z_3>$ chain (C_3)

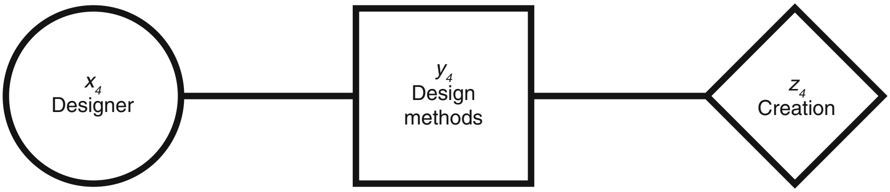

Fig. 7 $<x_4,y_4,z_4>$ chain (C_4)

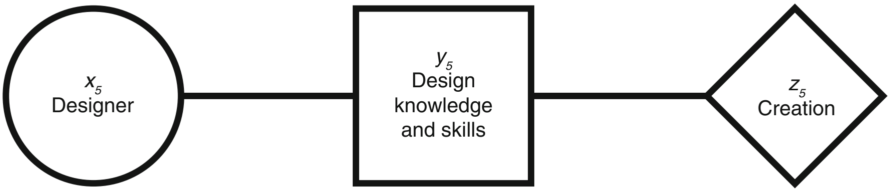

Fig. 8 $<x_5,y_5,z_5>$ chain (C_5)

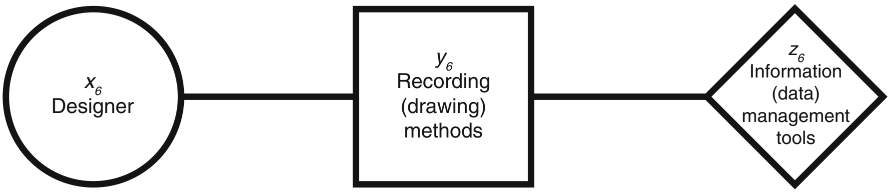

Fig. 9 $<x_6,y_6,z_6>$ chain (C_6)

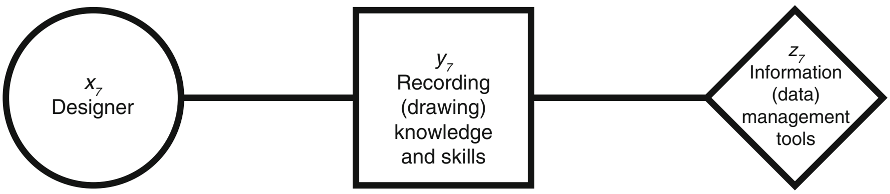

Fig. 10 $<x_7,y_7,z_7>$ chain (C_7)

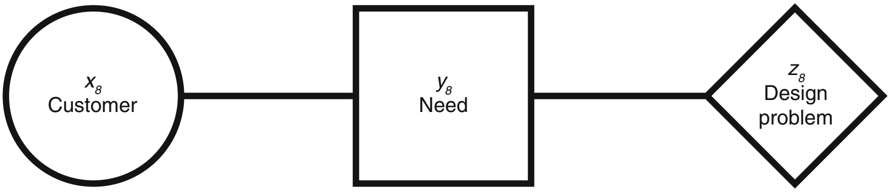

Fig. 11 $<x_8, y_8, z_8>$ chain (C_8)

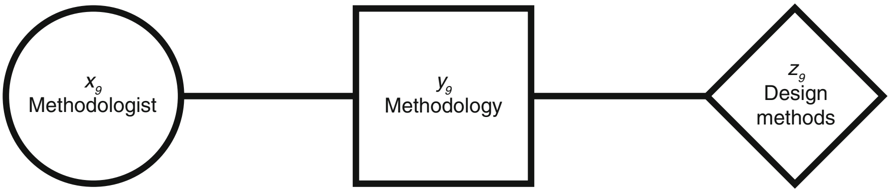

Fig. 12 $<x_9, y_9, z_9>$ chain (C_9)

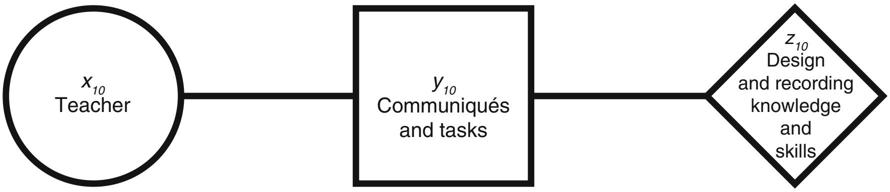

Fig. 13 $<x_{10}, y_{10}, z_{10}>$ chain (C_{10})

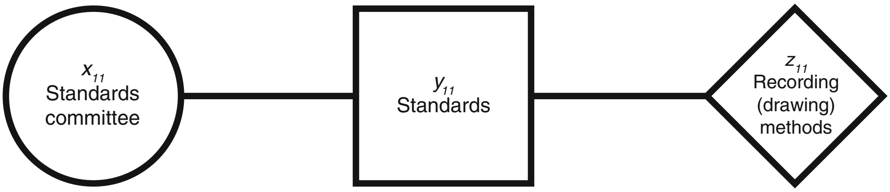

Fig. 14 $<x_{11}, y_{11}, z_{11}>$ chain (C_{11})

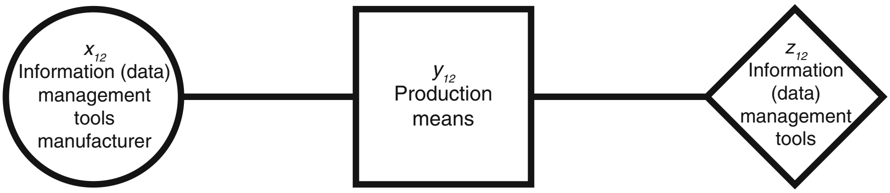

Fig. 15 $<x_{12}, y_{12}, z_{12}>$ chain (C_{12})

Because of the supportive relations between different chains, the Eqs. 6–12 referring to the presence of some elements in more than one chain may be written.

$$y_1 = z_3 = z_4 = z_5 \tag{6}$$

$$y_2 = z_1 = z_6 = z_7 = z_{12} \tag{7}$$

$$y_3 = z_8 \tag{8}$$

$$y_4 = z_9 \tag{9}$$

$$y_5 = z_{10} \tag{10}$$

$$y_6 = z_{11} \tag{11}$$

$$y_7 = z_{10} \tag{12}$$

Because of the character of the actions which are to be performed, the designer, present in a number of chains, is considered as one and the same person. Therefore, the Eq. 13 could be written.

$$x_1 = x_2 = x_3 = x_4 = x_5 = x_6 = x_7 \tag{13}$$

The $<x_1,y_1,z_1>$ and $<x_2,y_2,z_2>$ chains (C_1 and C_2) are the ones most directly related to the design process but their proper functioning is impossible without the support from the other chains, and especially the ones directly linked to them.

The $<x_2,y_2,z_2>$ chain (C_2), shown in the Fig. 4, represents the action of preparing (often writing down or drawing) a communique which is a message that may be filled with information or disinformation [6]. This action cannot be done without proper tools that allow one to present the creation [6] (the developed solution) in a way enabling sharing it with other people.

The $<x_1,y_1,z_1>$ chain (C_1), presented in the Fig. 5, is a model of the action directly supporting the action $<x_2,y_2,z_2>$ (C_2). The designer, aware of the developed creation which is a set of features being the object of identification in cognitive and creative processes [6], steers the operation of the data management tools while recording the obtained solution.

The $<x_2,y_2,z_2>$ (C_2) chain, though representing the final action within the analysed part of the whole designing process, is labelled as 'a second chain'. The $<x_1,y_1,z_1>$ chain (C_1), being a model of devising, is labelled with '1' index because it represents an action prior to recording.

The $<x_3,y_3,z_3>$ chain (C_3), shown in the Fig. 6, represents the action of considering and analysing the design problem (and therefore all of established assumptions) while working on the creation.

The $<x_4,y_4,z_4>$ and $<x_5,y_5,z_5>$ chains (C_4 and C_5), shown in the Figs. 7 and 8, are the models of other actions performed by the designer which support the development of the desired solution. These actions include the use of proper, general and specific design knowledge and skills as well as the introduction of design methods within the design process. The design methods, wherever it is necessary and justified, should refer to inventive methods, TRIZ and ARIZ (cf. [11, 12, 15–18]) which increase the effectiveness of the conducted inventive processes.

A similar situation occurs while elaborating the communique. The designer needs proper recording (which is often drawing) knowledge and skills and should be aware of the currently required recording methods in order to support the use of the data management tools. It is represented by the $<x_6,y_6,z_6>$ and $<x_7,y_7,z_7>$ chains (C_6 and C_7) shown in the Figs. 9 and 10.

The design problem is generally delivered by a customer referring to his or her needs (these could be the customer's needs predicted by the designer as well). This action is modelled with the use of the $<x_8,y_8,z_8>$ chain (C_8) presented in the Fig. 11.

The design methods are the object of the work of a methodologist, in general. The methodologist uses the models, instruments, methods and theories provided by methodology and praxiology as shown in the Fig. 12 presenting the $<x_9,y_9,z_9>$ chain (C_9).

Development of knowledge and skills of a designer is the result of his or her experience as well as proper education. The action performed by a teacher using appropriate communiques and tasks (exercises) in order to share the knowledge and develop the mentioned skills is modelled with the use of the $<x_{10},y_{10},z_{10}>$ chain (C_{10}).

The $<x_{10},y_{10},z_{10}>$ chain (C_{10}), shown in the Fig. 13, is a simplified model of a couple of chains. Both of them include one and the same subject and one and the same tool but refer to two different objects. The first of them are design knowledge and skills and the second are recording knowledge and skills. To simplify the description of the model, both of the chains, present in the Fig. 3, are shown as the one and only chain in the Fig. 13.

A typical situation in the field of technology is that some aspects of developed solutions should meet the requirements of standards and regulations. An example referring to the fact is the action performed by the standards committee which supports the action of elaborating the communique by introducing standards that affect the recording (and especially drawing) methods used by the designer. The action is represented by the $<x_{11},y_{11},z_{11}>$ chain (C_{11}) shown in the Fig. 14.

The action performed by a data management tools manufacturer is another support for the action of elaborating the communique by the designer. It is represented by the $<x_{12},y_{12},z_{12}>$ chain (C_{12}) shown in the Fig. 15. The tools manufacturer is able to provide the tools essential for recording the obtained solution thanks to the operation of the production means.

A simplified form of the described model, presenting only the supportive relations between the chains, is shown in the Fig. 16.

According to the existing conditions, more chains could be indicated and included in the model in order to analyse or synthesise a designing process more effectively.

An exemplary application of the model was conducted in reference to the creative actions during designing a manufacturing process of a combustion engine

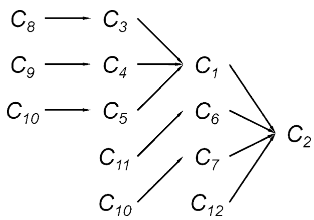

Fig. 16 A model of the supportive relations between the described chains

crankshaft. It is presented with the use of the following list of incorporated elements (cf. Fig. 3):

- $x_1, x_2, \ldots, x_7$—forging, machining and heat treatment process engineers (production engineers)
- x_8—crankshaft designers
- x_9—design methodologist
- x_{10}—mechanical engineering teachers
- x_{11}—national standards committee and company groups for standardisation
- x_{12}—software, hardware and drawing instruments and materials manufacturers
- y_1—crankshaft manufacturing (production) technology
- y_2—software, hardware and drawing instruments and materials
- y_3—a combustion engine part manufacturing (production) task
- y_4—manufacturing processes design methods and TRIZ
- y_5—manufacturing processes design knowledge and skills
- y_6—recording methods for a manufacturing process documentation
- y_7—recording knowledge and skills
- y_8—crankshaft constructional documentation
- y_9—praxiology and general design methodology, systems engineering, cybernetics
- y_{10}—communiques and tasks used during education process
- y_{11}—standards applying to the crankshaft production documentation
- y_{12}—production means used for the hardware, instruments and materials production as well as equipment used for the software development
- z_2—crankshaft manufacturing process documentation (production documentation).

The Eqs. 6–13 apply to the presented example.

4 Conclusions

It has been proved that creative actions may be modelled using a system of praxiological chains.

The proposed model allows one to present the actions supporting the analysed or synthesised design process during its organisation, modernisation and/or evaluation. Therefore, it could be used in order to identify:

- the actions
- the subjects (the people)
- the tools (as well as the methods)
- the supportive relations

which are essential for the effective realisation of the design process as well as the creative actions within it. The identification of these elements in a real, specific circumstances should deliver new possibilities of a better organisation of the design process. Therefore, the process should include all of the actions and only the actions which appearance is justified by the model in these circumstances. Such a state results in:

- a lower time required for the development of a new solution
- fewer mistakes occurring during the design process
- and consequently a more effective work of the people involved in the process as well as a cost reduction or a quality increase.

What is more, the model shows that the one and the same designer is involved in a huge number of actions. The fact could be considered as a reason for some difficulties which occur during a design process. The more properly the designer's actions would be arranged and supported, the more effectively the design process could be realised.

According to the solution presented using the chain $<x_4,y_4,z_4>$, the model may be used for rational and proper implementation of design methods and TRIZ in different types of design processes.

The presented model may be further developed in order to identify more actions (and therefore more chains) which support a design process, especially in specific circumstances. Another way of its development could be connected with performing the analysis of a design process conducted by a group of designers or including some of the features typical for a sequential-iterative (design) process in such a model.

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A Long-Term Strategy to Spread TRIZ in SMEs. Analysis of Bergamo's Experience

Davide Russo, Daniele Regazzoni, and Caterina Rizzi

1 Introduction

The worldwide dissemination of TRIZ in recent years is well known and documented. Often it starts with an enthusiastic phase of expansion and then gradually falls into later years.

Those who have studied this phenomenon [1] identified the main cause to TRIZ limited diffusion as the lack of truly effective training.

On one hand, there is a huge quantity of literature about TRIZ and a reasonable good part of it is high quality and suitable to attract newcomers. On the other hand, the educational side is not as good; real training and exercise books are not available, at least in a shared recognized form. The method itself is not universally accepted in a common version and there are a number of variants, also for the theoretical aspects. A TRIZ body of knowledge [2] has been proposed but it not universally accepted among the three main international TRIZ associations. There are divergent visions between experts from academia and from industry, between purists who barely accept any change in the method and practitioners who push the integration with other well-known and accepted practices. Moreover, some experts and educators trust a certification-based system while some others do not. Up to a certain extent, diversity of opinions and point of view is a resource for a positive debate and constructive comparisons of ideas, but this should rely on a shared and stable kernel on which anyone agrees. Cultural and geopolitical reasons affect the way TRIZ is taught and learnt in different countries. Newcomers after a successful basic course are often disappointed when trying to autonomously solve real problems and the level of enthusiasm quickly drops. This is one of the main causes that prevents systematic innovation from gathering the proper level of diffusion in industry.

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This thesis is supported and quantitatively validated by three different surveys carried out by Spreafico in 2015 [3], Ilevbare in 2013 [4], and Cavallucci in 2009 [5]. They conducted a deep analysis on heterogeneous samples of TRIZ users by studying scientific papers with case studies, questionnaires to LinkedIn TRIZ groups and interviews to participants of TRIZ conferences.

The three surveys agree that a small minority of users follows the entire method from the first to the last step. On the contrary, the majority of experts interviewed elects a small subset of tools, sometimes personalized, and integrates them with some other tools they already use in their professional life. In other words, TRIZ is mainly used as a large toolbox where single tools can be pick up and freely adapted to any specific situation.

Consultant companies as well follow the trend of differentiating their approach to TRIZ problem solving to create and propose their own method. Such process follows market rules and sometimes this is in opposition to Altshuller's ARIZ last version dated 1985. This cannot be avoided and it further increases the complexity of the overall picture preventing the definition of a solid body of knowledge on which everybody can converge.

A positive contribution is provided by some work groups belonging to the scientific community that are trying to increase TRIZ recognitions as a method for systematic innovation within national and international standards, in particular in Europe and Australia. Together with these initiatives, local institutions and universities accomplish a huge number of teaching and tutoring activities towards industry.

This paper is focused on a specific action to promote TRIZ diffusion on a local area that was conceived in 2009 and is characterized by some inedited features making it different from other known activities.

This program has been realized by means of a synergic collaboration among University and local institutions. It has a long-term perspective and, most important, an indirect strategy to spread TRIZ. Actually, TRIZ is not directly promoted, but companies are involved leveraging their interest in intellectual property and patents. The program offers basic services and companies are naturally prone to ask for them and to get in touch with the program.

The promising results achieved so far are the reason why we decided to share this model and our experience, hoping that it may be applied in other regions to gather the same benefits.

2 TRIZ and Industry in Italy and in Bergamo

Nowadays, it is particularly difficult to determine the real use of TRIZ in Italy because there are no official indicators. Since 2004, Italy has hosted two ETRIA international conferences, organized by the University of Florence in 2004 and by the University of Bergamo in 2010. Florence, Bergamo and Milan are the three main reference academic centers, while consultant offices are spread on the territory, mainly in the regions of northern and central Italy.

Up to 2015 there was also an Italian TRIZ Association, called Apeiron, Reason-based Association for Innovation, born in 2003 from an initiative of a group of people from industry and academy, sharing an interest toward systematic innovation methodologies and, in particular, TRIZ. Apeiron mission was to promote development and diffusion of scientific and technical knowledge of systematic innovation and problem solving. Today, there are a number of dissemination events organized by trade associations, professional associations, chambers of commerce, public and private training centers; however, a national or regional coordination to foster the visibility of the method is completely missing. Moreover, the potential industrial target constitutes another challenging issue that is the topic of next section.

Unlike other countries in the world (USA, Japan and South Korea) and in Europe (Germany and France), in Italy TRIZ did not have the same diffusion.

The general mistrust towards the method may be due to socio-cultural factors that characterizes Italian inventors and creatives. A part of the Italian industry, especially in some sectors (e.g. luxury, industrial design, furniture and automotive) is known throughout the world for its style and creativity. They prefer to think that idea generation is closer to an artistic activity or at least craft, rather than a systematic process.

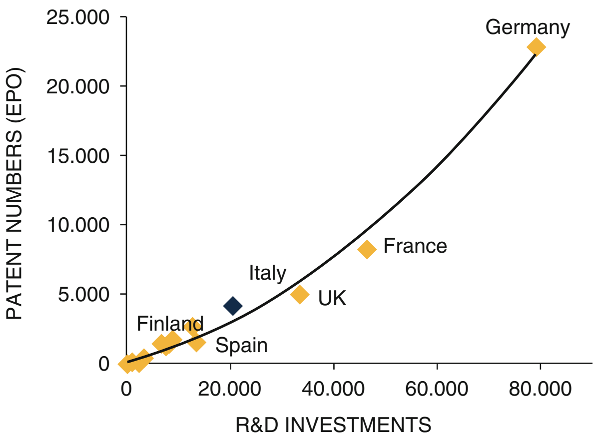
The very high presence (95%—about 4.2 million) on the national soil of micro enterprises (with less than ten employees) is clearly a vector of this mentality. Just think that they absorb almost twice as much (in percentage) of employees, compared to the European average.

Moreover, their minimal organizational structure makes it difficult to support investments for innovation or the introduction of new methodologies, as it happens more easily in large companies.

Furthermore, the industrial distribution of Italian companies should also be considered. In fact only 12% of companies operate in the manufacturing sector, an optimal target for TRIZ, while there are much more companies operating in other areas like business (28%), agriculture, livestock (18%) and building (15%).

However there are encouraging factors. If we analyze the data of the Italian National Institute of Statistics (ISTAT), (Fig. 1) [6] it can be seen that Italian companies are

Fig. 1 European R&D investments and patent number filing



above the European average as the number of patents per capita, despite the R&D spending is not high and is decreasing.

This means that even smaller companies, which have reduced time and human resources available for training on methods like TRIZ, developed a valuable sensitivity to the theme of innovation, with particular attention to industrial property issues.

To date, the province of Bergamo holds almost 13% of the manufacturing industries within the national territory, subdivided into small ones with less than ten employees and SMEs. The latter in particular concentrated in a very restricted area and within an enlarged industrial territory with three university (Bergamo, Milan and Brescia) over a distance of 50 km.

In Bergamo, the Chamber of Commerce, and in particular its special agency (called Bergamo Sviluppo) and the local University have promoted a long term project for the introduction of TRIZ. It works through the promotion of courses, seminars and consultancy addressed to companies and students. In the following, the different activities are explained in detail.

3 The Bergamo Model: Chamber of Commerce Activities

The Chamber of Commerce activity has been developed in collaboration with the University of Bergamo and has the objective of promoting the protection and promotion of Industrial Property in the territory, in a structured program that can be potentially replicable as it is in other geographic and industrial districts [7].

The project comprehends different programs dealing with patents and TRIZ.

3.1 Exploitation of Industrial Property Guidance and Customized Technical Support Service

As far as intellectual property is concerned, the Chamber of Commerce model proposes various individual and group activities, dedicated to SMEs and artisans from different sectors.

The courses and collective seminars, organized at different times of the year, are dedicated to the techniques and tools of patent research: prior art, freedom to operate and technology transfer.

The service that is instead carried out on an individual level, used by more than 300 participants since 2011; it takes place on a monthly basis and consists of different types of activities. The most required is the orientation on the best strategy of protection for the user's ideas, suggesting what type of protection and the modality of deposit, discussing about the patent inventive unity or the content of the main claim. This is the first opportunity to talk about TRIZ, and show them its potentiality.

3.2 Education and Dissemination Actions on Intellectual Property and Innovation

The technical assistance is supported by several activities and a variety of training activities, as follows:

- One seminar per year to promote the project.
- Two basic courses per year (lasting 3 days each) dedicated to patent search, explaining techniques and tools to perform patent research independently, (e.g., prior art or freedom to operate searches) and also techniques and tools to exploit patent database to benefit from design of analogy and technology transfer opportunities.
- Four advanced seminars per year on the topic of: "Patents as a means to innovate and problem solving tools (TRIZ) based on patents".

Seminars and courses attendees increase every year coming from different industrial sectors and with different roles inside the companies.

3.3 TRIZ Course and Tutoring

The aim of the TRIZ course is to infuse the basic concepts of problem solving within a systematic methodology. It is designed specifically for entrepreneurs and R&D technicians and its structure is divided into four phases.

Every year a 40 h course on SPARK methodology [8–10] is provided to 10–15 participants. SPARK integrates TRIZ tools like Film Maker (that is an evolution of TRIZ Multiscreen), Ideality, Laws of Evolution, Resources, Functional analysis, Contradictions, Inventive Principles and Standard Solutions with new strategies for the management of product/process/service requirements (e.g. Market Potential) and tools for knowledge retrieval (e.g. Effects DB and Patens DB). The combination of these modules represents the synthesis of a TRIZ experience gained in over a decade of consulting with hundreds of companies, through teaching systematic innovation in several official university courses and discussing with PhD students and research assistants in the university laboratories.

SPARK combines the rigidity of a step by step method with the flexibility required in the more conceptual phases. Five steps, each one with a specific goal to be reached in order to reformulate the problem and then solve it. For each step, you can use all the suggested TRIZ tools in a free and independent way.

In Fig. 2 an infographic shows how TRIZ tools are organized according to this framework: (1) Functional framing of the product, (2) Evolutionary framing, market position and final goal definition, (3) Identification of the best moment and the most suitable level of detail to solve the problem, (4) Formulation of the problem in terms of physical contradiction, (5) Identification of the solutions and the defense strategies.

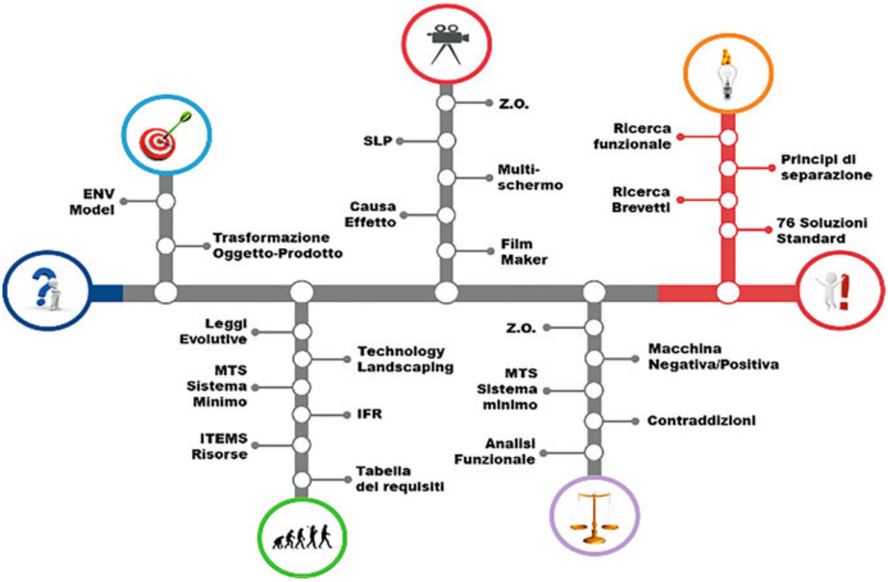


Fig. 2 SPARK methodology scheme

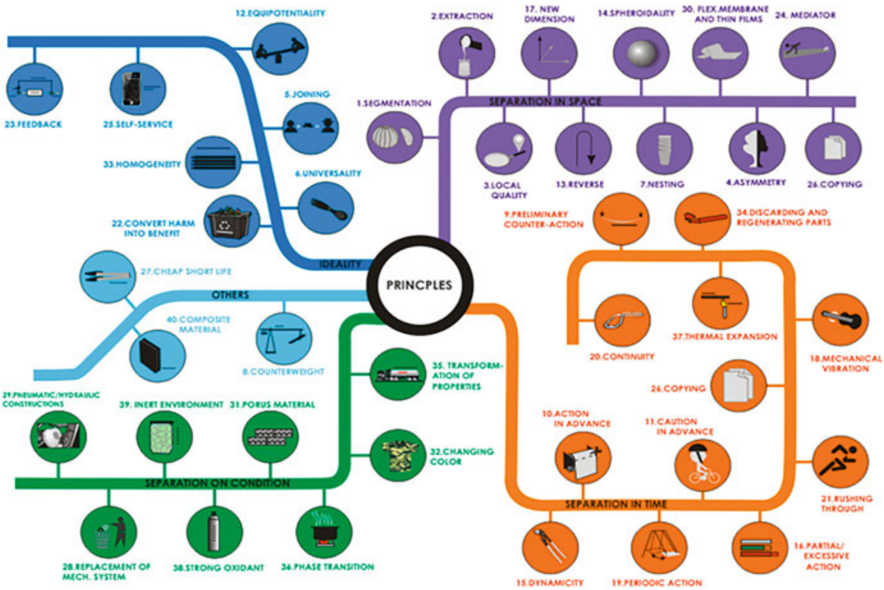


Fig. 3 Infographics for TRIZ fundamentals fixation

Most of traditional TRIZ tools have been translated into infographics and inserted into a cognitive path designed to improve learning and fixation.

Figure 3 shows the infographic about separation principles, which are inserted within five thematic lines in a scheme based on the analogy with the Metro Map.

4 Bergamo Model: University Activities

The University of Bergamo offers both academic courses and consultancy for companies.

4.1 *University Teaching: Courses, Seminars and Masters*

At the University of Bergamo, there is an 80-h course called "Product and Process Innovation". It is part of the Master's Degree in Mechanical Engineering and is totally dedicated to TRIZ. It also includes the rudiments of conceptual design (i.e. Function-Behavior-Structure) and information retrieval.

Every year, the students enrolled in the course are on average fifty.

To pass the exam students must carry out an individual project based on a real industrial case and articulated through the following phases:

1. **Information gathering** about problem to be solved. R&D manager of the company involved, at the end of the course presents to the students his case study, during a frontal meeting of 2 h.
2. Students collect information and then has 2 weeks for **solving the problem** autonomously, applying Spark and no longer having any contact with the owner of the problem or the professor.
3. **Results Presentation**. Students present a report explaining how they applied the methodology. The final results are instead synthesized in specific template simulating a technical presentation for promoting the proposed solutions at a commercial level. It consists of a double-sided A4 sheet containing on the first page a brief presentation of the initial problem, the main requirements achieved, and a concise summary of the working principle adopted for realizing the goal. On the second page, the solutive direction is described at a deeper level of detail, including sketches of the designed structures and possible variants.
4. **The evaluation of the project** is carried out by the professor, both taking into account how correct the application of the methodology has been, and the adherence to the company goal. The results are also presented and discussed with problem owners. Companies can reward students with the best solutions or involve them as inventors in case of patenting filing.

The following figure (Fig. 4) shows an example of an A4 flyer.

In addition to the above-mentioned course, the University of Bergamo also offers other course where TRIZ is somehow treated. For example, "**Product Lifecycle Management**" course for Management Engineers contains a module based on TRIZ strategies about the use of patent knowledge for supporting technology transfer.

In addition until 2017 there was the higher education course "Entrepreneurship and Innovation for SMEs Internationalization, **Go.In '—Go International Be Innovative**" carried out in collaboration with the Chamber of Commerce and

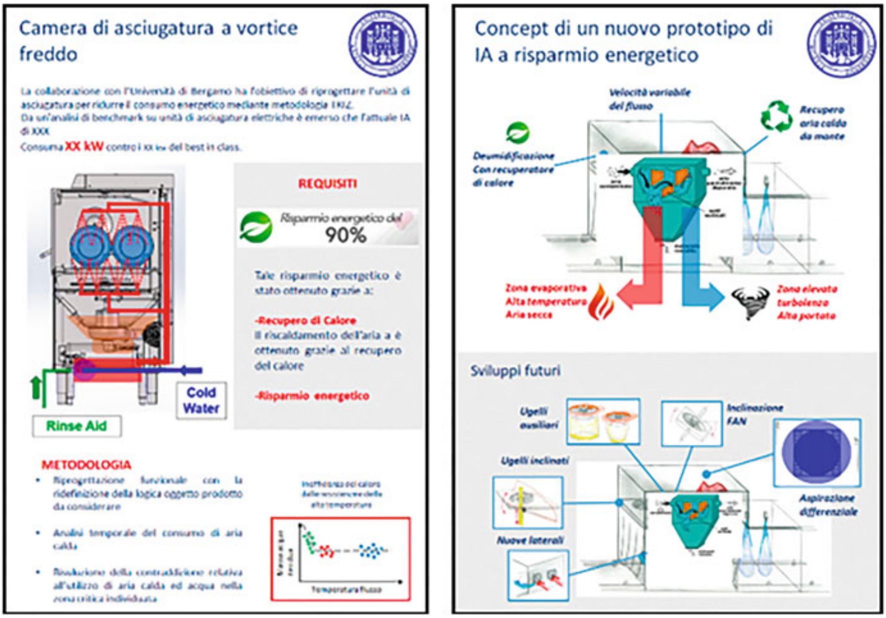


Fig. 4 Example of A4 Flyer for solutions presentation

aimed at 40 young entrepreneurs from family businesses and start-ups selected each year on the territory. Of the total 180 h, the course included 20 h related to TRIZ and patents.

4.2 University Consultancy and Professional Associations

Italian universities in addition to research and teaching activities, pursues the so-called “third mission”, concerning the promotion, the direct application and enhancement of knowledge to contribute to the social, cultural and economic growth of enterprises. Any institutional structure within the University is committed to communicate and disseminate the knowledge through a direct relationship with the local industries and with all its stakeholders.

Within this context, in the last 10 years, the University of Bergamo has launched close collaborations of research based on TRIZ and Intellectual property management with important companies both in the territory and outside (e.g. ABB, Coesia Group, Imetec, ST Microelectronics) and many other smaller enterprises.

Finally, there are also occasional TRIZ education courses dedicated to professional associations (mostly for engineers). Participants are professionals who run their own activity and who are approaching TRIZ moved by curiosity more than by a real need. However, also this activity it is important to feed a promotion mechanism based on word-of-mouth.

5 Achieved Results

From the beginning of this activity to today, there have been several positive results that confirm the success of these activities with University and the Chamber of Commerce. Many indicators confirm that this collaboration is effective.

For example, events held by the Chamber of Commerce have more chances to be advertised and promoted in local newspapers and professional associations, compared to university initiatives. In recent years there were many articles dedicated to our initiatives on TRIZ in local newspapers. Among them, the most significant are interviews to companies reporting their experience in training and using TRIZ in the everyday activities.

From our perspective, the successful story of real cases, even in micro and small enterprises, is the most effective communication channel. Definitely, they give credibility and authority to the method and to trainers, much more than any other communication means.

Another significant achievement consists in the number of patents filed by companies. Although this parameter should be evaluated on a longer-term perspective, the signals of the increase in the number of patent filed by companies of the territory are already well visible, even if not necessarily attributable exclusively to the project.

Figure 5 shows the number of patents, utility models and industrial designs in the province of Bergamo from 2005 to 2014.

The measure of this return is certified from the fact that the technical assistance on Intellectual Property is carried out in collaboration with the experts of the

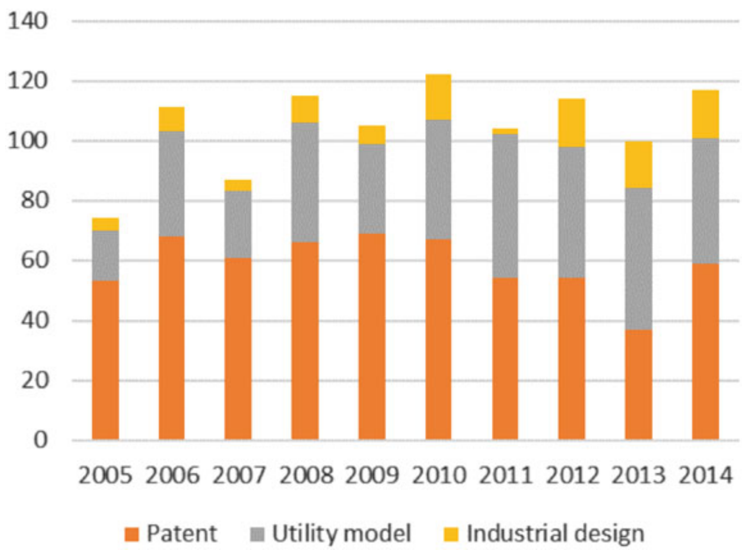


Fig. 5 Patent filing at Bergamo patent office from 2005 to 2014

Trademarks and Patents Office that participate to the meetings. The same experts are those involved in the patent filing activity and, thus, they meet once again the inventors and have the chance to directly measure the impact of the project on local patents.

Another indicator is the growth of the number of companies and inventors participating to the Exploitation of Industrial Property guidance service. The number increased from 4 to 12 people per month, on a relatively small territory.

The quality of the ideas is evolving. Compared to the past applicants often has already conducted an accurate prior art search before filing their patent. This is an important signal of the fact that in a few years the innovation culture has globally grown in all its aspects. Actually, the skill of performing basic information search and to use patent search portals (e.g., Espacenet) has reached a broad diffusion even in micro enterprises and artisans.

An additional fact is the increased interest of enterprises to students who attended the TRIZ course at the University. Only few years ago, advanced TRIZ competences were taught only at PhD level while now companies are looking for these skills in master students. On the other hand, master degree students with a TRIZ course are more likely to be hired in R&D positions.

6 Conclusions

It is well known that the best way to spread a method is to find renowned industrial sponsors. This was seen in the past for example for Six Sigma and General Electric. However, in a region like Italy, dominated by SMEs, this model is not enough. We need also alternative strategies.

The project of dissemination of TRIZ carried out in collaboration between the University of Bergamo and the Chamber of Commerce began is an example. Since 2009 this project has provided a large number of initiatives using intellectual property as a means of bringing the company closer to the world of systematic innovation.

The key aspect of this dissemination project, is to not center all efforts on a direct promotion of TRIZ but propose a gradual approaching path made of small interventions, literacy courses that finally concludes with an extensive 40 h TRIZ course and an expert tutoring.

To convey TRIZ fundamentals, we were forced to rethink the teaching approach, update classical tools in order to integrate TRIZ within SME context. For example, SPARK, is the teaching module containing all TRIZ fundamentals opportunely organized according to a rigid sequential path that integrates the management of the marketing requirements and other tools for information retrieval (patents in particular).

Since 2009 this project has grown both as a number of activities and as participants.

Measurable indicators tell us that the results so far are good, the demand for innovation services shows no signs of diminishing, and feedback from the participants forces us to continue on this path.

This model could be replicated in other local areas that possess the same characteristics of Bergamo: the university with a strong expertise in TRIZ and a local organization used to thinking with long-term projects.

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Lessons for TRIZ from Design Thinking and Lean 3P

Michal Halas

1 Design Thinking (DT)

Design Thinking (DT) is a method of creating innovative products or services based on deep understanding of problems and needs of users. It was developed in California in the '80 and '90 of XX century. One of the main authors of DT is David M Kelley, designer, entrepreneur and professor of Stanford University, cofounder of "d.school" (Institute of Design Stanford University), friend of Steve Jobs and chairman of design company **IDEO**, using Design Thinking to create new products for companies like Apple [1], Shimano or GE [2].

David M Kelley recalls in interview [2] that Design Thinking was developed from necessity of changing the old model of cooperation client-designer. In the former times the technological companies were coming to designers with a ready product expecting only the nice casing. Often designers had brilliant ideas for the functioning of the product but there was too late for such changes. Design Thinking, by engaging the designers in the very early concept stage of the product is giving in reality far more innovative solutions.

In Design Thinking interdisciplinary team is going through five steps (Fig. 1), often in iterations of single phases.

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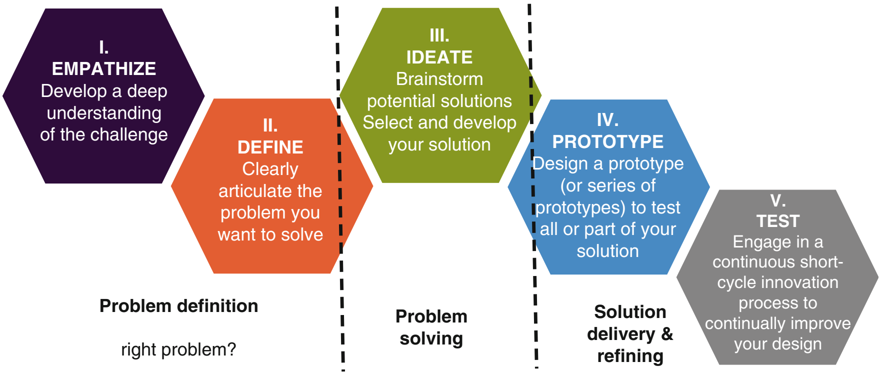


Fig. 1 Design Thinking Stanford Process (Source: educate78.org)

1.1 Strengths of Design Thinking

1.1.1 Empathize–How the User Feels?

Highest strength of Design Thinking in the opinion of the author is the Empathize Phase. Much effort from the very beginning is given to find not only the Voice of the Customer but what are his feelings and subconscious decisions. Different technics of empathizing are used to "enter the skin of the user". Results from this stage are determining where the project will finally land. Deep empathy shows the emotions of the user and helps to understand his needs.

In accordance with a saying "In the country of the blind, the one-eyed man is king", for commercial projects which were strong on empathy, it was a mighty weapon to defeat competitors who didn't care about the feelings of the user (Apple products were great example of this—some years ago). Although it seams, that business world learned this lesson by now, in 2016 there is not many blind to the issue of user feelings.

In the opinion of the author, empathy-centered tool may deliver low up to medium level breakthroughs (which is still a lot) because there are limitations to client's imagination (even the subconscious). As Henry Ford is quoted "If I'd asked people what they wanted, they would have said—faster horses".

1.1.2 Flexible and Simple

As design people are artists, you can't expect that the tool created by artists will be rigid. Design Thinking is one of the most flexible and simple methods for complete process of innovation, it can be measured by time needed to get to know this method. Simplicity is enormous advantage when you look at the current popularity of different New Product Development tools. Simplicity is in the denominator of the formula for ideal innovative tool, so it should not be overlooked.

1.1.3 Quick Wins

Design Thinking is NOT ONLY simple to grasp. It can demonstrate early benefits very quickly and it is important business reason for choosing DT for innovating. There are often many "low hanging" fruits for a company which earlier was not paying attention to the emotional area of users.

1.1.4 Agile Prototyping

Design Thinking emphasizes the "doing" not only thinking or writing or even sketching. Making tangible models and (usually many) working prototypes to refine the solution makes possible better testing of the market product anticipation, and thus ensuring sales. Tools known from Agile Project Management are employed to deliver quality solution very fast which is still novelty for some companies (Fig. 2).

1.1.5 Good Marketing

Finally Design Thinking is having a very good PR. You can expect from design gurus that they will do their best to market Design Thinking as a training/consulting product. In the opinion of the author they did really well. As one comment, found on internet on comparison of DT & TRIZ says: "*I see neophytes in the office, actively spreading the gospel of design thinking process with eyes shining brightly. TRIZ proponents are not nearly as active*" [3].

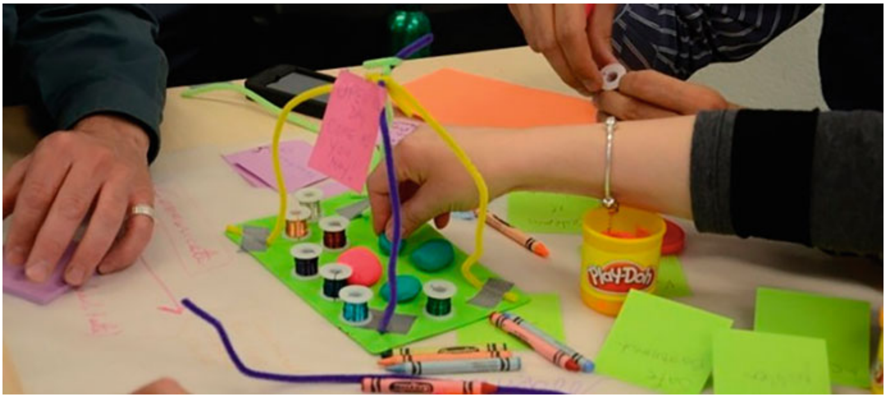


Fig. 2 Using easy available materials to make prototypes is characteristic to Design Thiking (photo source www.exhibit-change.com)

1.2 Weakness of Design Thinking

1.2.1 Limited Area

While Design Thinking, works best where there are important human interactions, it's strengths are fading in other situations (eg. robotized manufacturing). The trend of growing automatization is pushing Design Thinking only to this areas where there are human interfaces. This is still a lot of areas, so tools based on empathy shall not die in near future.

1.2.2 Poor Creative Engine

Design Thinking relays in its "Ideate" stage on brainstorming technique or simple creativity methods such as Mindmap or at best SCAMPER [4]. The simplicity of such tools fueled the market popularity of Design Thinking, especially among the non-technical and non-scientific minds. But still it is an obvious weakness [5]. Happily for DT practitioners there is TRIZ ready to be employed.

2 Lean 3P

One of the finest tools of Lean philosophy is 3P (Production Preparation Process).

3P was developed in post war Japan based on Toyota Production System. In the 1980'for the first time it was presented in the USA. If Japanese word KAIZEN means gradual and continuous improvements than 3P is about Japanese KAIKAKU which is breakthrough, revolutionary change. 3P can be used for new products but in this article it was narrowed down only to modifying or creating new lean production (or service) process. The development of 3P is attributed to "Father of Moonshine" Chihiro Nakao, student of Taiichi Ohno (creator of the Toyota Production System).

The basic idea of 3P is to achieve, in Mr. Nakao's words, "breakthrough or transformational changes in production process" through rapid, integrated prototyping of both product and process [6].

2.1 Strengths of 3P

2.1.1 Lean Results

A tool from Lean manufacturing philosophy cannot waste time or money. It applies saying "use your wits, not your wallet". According to George Koeningsaecker "With 3P, you can normally get a given increment of capacity at one-quarter the capital cost of traditional approaches, and you can normally get a fourfold productivity gain." [7]

2.1.2 Cheap Workforce–Close to Final Users

Similar to Design Thinking, 3P is employing rapid prototyping but is using mostly shop floor people, although they might be not highly educated, but are usually experts of the manufacturing processes to be changed. In point of fact they can be named final users for such manufacturing processes. In this case 3P is engaging final users to the maximum. Especially for such people usage of pictures is encouraged (so you don't have to know special terms to show an idea). When the final prototype is positively verified than second class engineers (cheap again) can transform it into real thing.

2.1.3 Gemba (Close to Workshop)

As Design Thinking is centered around final customer and his emotions, 3P as every Lean tool is strongly connected to Gemba (place where the particular process occurs). Gathering all information in the very beginning of 3P process might not be so funny as empathize part of DT, but as author observed, is very effective in getting brilliant solutions.

2.1.4 Moonshining–Around Bureaucracy

Moonshine according to Mike Wroblewski is "1. A method of disruptive action that occurs in secrecy, under and around organizational boundaries and procedures, producing blast improvement to any process. 2. A Lean Manufacturing tool that uses fast and inexpensive prototyping to develop and prove a concept, prior to full implementation." [8]

Moonshining is a way of getting around the bureaucracy to speed up the development process. 3P Moonshining enables rapid refining of ideas through "try-storming" (derived from brainstorming) and "card board engineering" to mock up and simulate quick-and-dirty solutions [9].

2.1.5 Agile, Quick Prototyping

Moonshining is quick. Even the source of 3P and Design Thinking are very different, they both converge at quickly building models and prototypes which is absent element in TRIZ. When time to market is the most important factor, than this is life or death for a company.

2.2 Weaknesses of 3P

2.2.1 Rigid Structure

Stiff process can be looked at, both as a strength and a weakness. Contrary to Design Thinking, 3P is very rigid as many other Lean Manufacturing tools. You cannot go further without developing seven alternatives, similarly you have to select later exactly three alternatives. Sometimes there might be cultural problems with accepting the stiffness of such approach, but when you lack high quality facilitator for the process, than rigid plan may take you to the success.

2.2.2 Low Popularity

Other Lean tools are popular because of their effectiveness. 3P is not (at least in Poland). It may mean that 3P is either still at the beginning of its S curve, or will die surpassed by better marketed tools.

2.2.3 Limited Area of Use

3P is strictly connected to Lean culture. It is needed a very experienced 3P facilitator to do 3P with non-Lean people. Author seen best results of 3P in company which added 3P to former 10 years of deep experience in Kaizen. So it seems that 3P use is limited to Lean enthusiasts for best results.

2.2.4 Idea Generation Engine

3P is employing biomimicry (biomimetic) for generating new ideas.

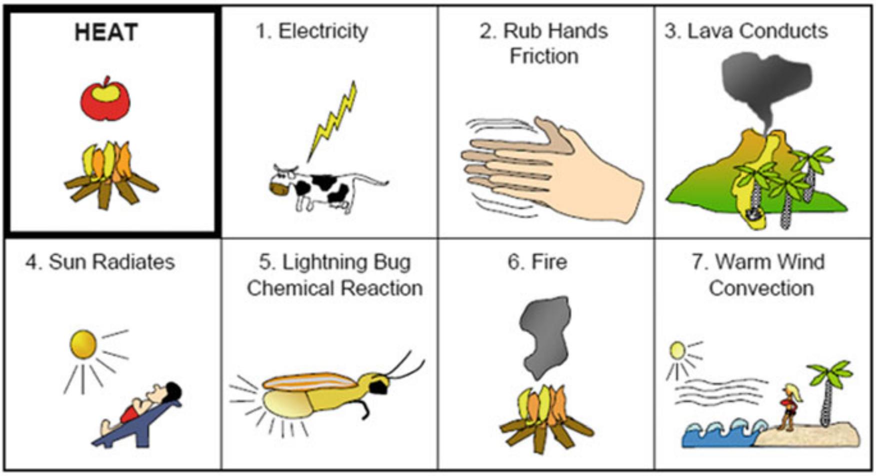
On Fig. 3 are more detailed steps of 3P with pointed idea generation engine. Similarly to Design Thinking, 3P is very good at fast prototyping (try-storming, moonshining) and testing ideas. Idea generation is based on simple inspirations from Nature which is different to brainstorming of DT.

Although inspirations from nature (Fig. 4) gave many great outcomes, TRIZ is tested as potentially far better idea generator for 3P. The problem is, that if the strength of 3P is employing not educated people, than some TRIZ tools might be too difficult to use. Further research to overcome this contradiction is to be made.

1. Determine Function
2. Collect "Real" Data
3. Develop "7" Alternatives
4. Examples in Nature
5. Moonshine
6. Evaluate "7" Alternatives
7. Select "3" Better Alternatives
8. Construct Model Operations
9. Simulate "3" Alternative Processes
10. Select "1" Best Design & Process Combination
11. Create Standard Work
12. Develop Equipment Concepts
13. Develop implementation Plan
14. Follow Up!

(Steps 3–4: Idea generating Engine of 3P)

Fig. 3 Steps of 3P from Mike Wroblewski_Gemba Consulting_LM.pdf at www.reliableplant.com



7 PROCESS OPTIONS FOR: HEAT							
Material	High Voltage Electricity	Microwave Heat	Conduction Heat	Radiant Heat	Exothermic Chemical Reaction	Fire	Convection Heat
Method	Arc Welder	Microwave Oven	Deep Fryer with Butter	Infrared Oven	??? X	Pizza Oven or Broiler	Convection Oven

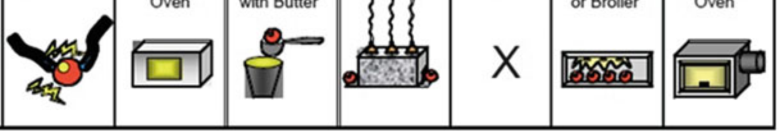


Fig. 4 Example of seven alternatives derived from nature for heating process (from Allan R. Colleta) [11]

3 Convergence of Design Thinking and 3P with Comparison to TRIZ

Although Design Thinking and 3P are from different cultures and communities (California designing vs. Japanese production) they show outstanding convergences to each other and are significantly different to TRIZ.

- Both are strong in **employing final users**. In Design Thinking several tools are used to get info about final customers (and their feelings) so this works best with products aimed in B2C environment. 3P when used for B2B production (or service) is using shop floor workers who know the process first-hand and is being as close to gemba as possible. This means again being close to final users. Although TRIZ may offer something for problem definition it is not as good in encouraging strong link with final user or gemba aspect.
- Both are horizontally **complete processes** starting from problem definition through simple idea generation, further relying heavily on rapid prototyping and testing with mock ups to finally produce at least proved prototype (or final product). TRIZ in comparison is not complete, needs front and back phases to be comparable.
- Both are **cutting development time by doing trials** by teamwork in separated space. Both are designed to go around bureaucracy. TRIZ is not addressing prototyping and the bureaucracy issue at all.
- Both are using **simple creativity tools**. Simplicity in idea generation is an entrance benefit on the market but later may not help to receive high level solutions. These leads to possible synergy between TRIZ and both DT and 3P. Here TRIZ offers better innovation tools, but some of them are difficult to grasp.

4 Lessons for TRIZ from Design Thinking and 3P

4.1 Synergy of TRIZ with Design Thinking or 3P

Easy of use of original problem-solving part of Design Thinking was strength at the beginning of "S" curve of market proliferation of DT. It could be boosted now by adding more powerful problem-solving engine. TRIZ tools were successfully tested in conjunction with Design Thinking [4] and how this full scale synergy is received by the market is still to be seen. Change from easy to more sophisticated tools might not be easy, and response from business world will be what finally counts.

Similarly 3P could benefit by use of far stronger idea generation engine like TRIZ. The only problem is difficulty of use of some TRIZ tools in opposition to uneducated workforce used for 3P. This contradiction is waiting for resolution.

Worth mentioning are TRIZ tools which could enhance the beginning of the NPD process (empathize or "collect real data" in 3P). For example TRIZ 'Voice of the Product' could be used in this early stage.

4.1.1 TRIZ as Sophisticated Engine–Not a Complete Process

If New Product Development (DT and 3P are good examples) is compared to an aircraft than TRIZ will be as sophisticated engine. For some aircrafts very sophisticated engines will be used, some others need simple and easy engines. Author believes that TRIZ should be known to the market as brilliant, sophisticated idea generating toolbox ready to work with more complete processes like DT or 3P. As Kyeongwon LEE writes "TRIZ is one method and process for just conceptual stage" [4]. TRIZ is missing the further solution delivery with refining stages and is not best at bringing the user close to problem definition and solving. So you cannot oppose DT to TRIZ or 3P to TRIZ, aircraft should be compared with aircraft, engine with engine.

TRIZ in early years was presented as fast alternative to "trial and error" method. It is true, that TRIZ can reduce significantly the number of trials, but you finally have to prove the idea with some kind of prototype. Synergy between both DT and 3P with their agile rapid prototyping and TRIZ (which is not having such tools) is evident. In this way, weaknesses of TRIZ can be strengthened when sophisticated engine is applied to complete aircraft.

Here is illustration of this point: Kalevi Rantanen and Ellen Domb in their book "Simplified TRIZ" mention a Standard Story coming from their consulting experience:

"*Companies tell us this story so often we have named it the "Standard Story"—A competitor introduced a new solution and we found the same idea in our own notes from many years ago*" [10]. Finding a great idea is just the beginning, not an end to New Development Process. Without the good further steps we can lose at competitive market. DT and 3P provide further steps of solution delivery and refining.

As Rolls-Royce's company is known with their jet engines, it cooperates very well with renowned aircraft manufacturers. Similarly TRIZ seen as great idea generating engine might be a blessing to horizontally complete New Product Development tools like Design Thinking or 3P.

I don't agree that you should look at TRIZ to be compensated by Design Thinking as Kyeongwon LEE proposes [4] (or by 3P). It should be the other way round: Design Thinking, 3P and other complete New Product Development tools could be improved with sophisticated idea generating engine like TRIZ.

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TRIZ Potential for IT Projects

Monika Woźniak

1 Introduction

Information systems play a crucial role in knowledge-based and innovation-stirred economies. Over the last decade, there has been a systematic increase in IT project implementation in companies [1–4]. At the same time, a low rate of fully successful IT project implementations has been noted, alongside the problem of the latter not being tailored to the client's actual needs and that of inefficient communication within the IT manager—IT team—client triangle [2, 4, 5]. These observations pushed the worlds of business and science alike to undertake a multifaceted search for the causes and solutions within this realm, with special focus at the outset on technical aspects and the sheer methodology of project implementation. This approach, however, did not lead to any improvement in the assessment of success rates pertaining to IT projects. Next, following the analyses performed for the renowned International Journal of Project Management and Project Management Journal by Crawford, Pollack and England from 1994 to 2003 [6] and by Gemünden between 2000 and 2011 [7], the soft factors of IT project management gained ground in the studies. Among the factors enumerated most often as both critical success factors and failure causes are: the awareness of the client's role, communication and managerial support.

Studies within this dimension have resulted in numerous recommendations, which, unfortunately, are no more than wishful thinking. There is still no mutual understanding or cooperation between the creators of IT project products and their beneficiaries—the companies the projects are carried out for. According to reports on information systems, most enterprises use only about 10% of program functionalities to a significant extent [5]. Business expects IT to be more and more flexible.

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So claim international companies offering most comprehensive IT solutions, providing support for software management, incident management, problem management, configuration management, change management, version management and availability management.

In the meantime, also the perception of IT project success has evolved from the classic project triangle (i.e. time, budget, scope) [8] into a client inspired success and failure discourse [9]. In these circumstances a dialogue is rightly expected between the IT team and the client for more suitable products of the IT project in question. For this dialogue to be possible one needs proper awareness, space, common ground for mutual understanding and commitment of both parties. The literature of the subject and the author's IT project research indicate that the awareness of the need for this kind of dialogue is increasing. What is missing, however, is the common ground for understanding. It is a challenge for researchers to attempt to find a dialogue based language for as differing professional groups as the IT team and business.

2 Background

The implementation of an IT project in a company interferes more or less directly with business processes occurring there. Naturally, the company cohesion becomes subject to verification both in terms of the logic of its operations and the aspects of its organisational culture. This cohesion, as proven by the author's studies, translates into the final assessment of the IT project success [10].

In the period of 2012–2015, the author conducted studies relying on the unstructured interview method and participant observation. They concerned on IT projects implemented in the Polish SME sector as the service of providing software commissioned by the client, focusing mainly on the issues pertaining to the interaction in the triad of IT manager—IT team—client (here understood as the organisation at whose request the IT project is being implemented). Each of these entities represents a different organisational culture and professional identity [11]. Each culture incorporates a different value and communication system. The interviews and observations made in the course of implementing various IT projects revealed different communication flaws. Figure 1 shows the most frequently noted negative factors disturbing the relations within the IT manager—IT team—client triangle in the majority of the organisations under study in the period of IT project implementation. The direction of the arrow denotes the perception of negative aspects of the relationship with the entity pointed at.

The studies performed lead to the conclusion that IT teams create a strong counter-culture to IT managers. It is typical of the former to negate the power of the manager and to belittle his role if he does not have a detailed technical knowledge. A strong sense of professionalization of IT specialists' trade resulted in their focus on the sheer products of the project, indiscriminate attachment to these

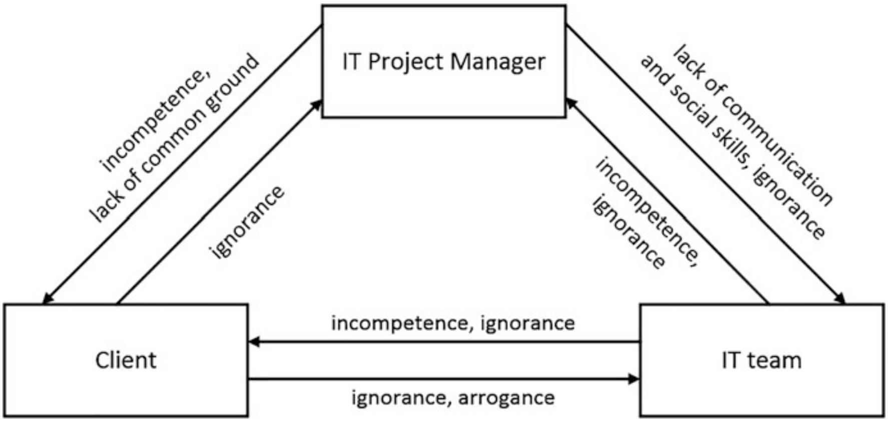

Fig. 1 Diagram of mutual perception of negative relationship aspects it IT projects under study. Source: own

products, authoritative formulation of product assessment standards and failure to meet client's real needs if not ignoring them altogether. The IT projects are lacking in support for a better understanding of the client's needs and in redefining the project requirements so as to make them better suited to the organisation.

Given these facts, it seems worthwhile to conduct studies on the improvement of the communication patterns of any IT project stakeholders [12]. A method would be desirable that would standardise the metalanguage of IT project communication and that could be applied, in terms of concepts and technology alike, in both the business area and IT. The method should not, however, be based on the IT language. For it to be accepted by IT people and, at the same time, easy to use for business people, it should be structured and lead to clear results.

3 Is TRIZ an Answer?

The morphology of the Theory of Inventive Problem Solving (TRIZ) appears to be similar to that of creating information systems within IT projects in an organisation. On the one hand, it is based on a creative process, and on the other, it has to take into account the limitations, contradictions and certain rules, which is a condition of creating a satisfying solution. In IT projects, however, one typically moves from a problem to a solution too fast, which lowers the efficiency of IT solutions in organisations.

TRIZ in Russian, the language of its creator H.S. Altszuller, is *teorija rieszenija izobratielskich zadacz* (a theory of resolving inventive problems). It was proposed in 1956 following many years of studies of over a million patents. Altszuller developed a set of rules and algorithms for identifying and solving engineering problems [13]. Subject to certain modifications, this method has been streamlined to date. And although it originated from an engineering background, it has also been applied in organisational, social and broadly defined business contexts. Little known in Poland and Western Europe, it has been successfully applied in well-known Asian, US and, obviously, Russian corporations. The rate of TRIZ application in a given country is positively correlated with an increase in the number of patents and the innovation rate.

IT projects stimulate the use of state-of-the-art technologies conducive to creative solutions. Unfortunately, most of them are burdened with the so-called inertia vector—inventors' preference to resort to the experience of previously applied professional practices in problem solving. However, the technological progress in IT projects is so dynamic that such solutions will prove neither innovative nor satisfying. It is enough to take a look at the most important aspects of IT projects in the pipeline [14]:

- large scope, untypical and unique character,
- high degree of complexity,
- high level of risk,
- relatedness to dynamically changing market and environment conditions implying the need for flexibility in IT project implementation.

Based on the proposed rules, TRIZ enables the identification of the so-called 'ideal final result' (IFR), which very often goes beyond the current cognitive zone of the individuals working on the problem. The approach offered refocuses the process of thinking, reduces the probability of randomness and narrows down the search area to that suitable for the solution sought for, which makes the entire process more effective. Thus the solutions that create new quality are promoted, which constitutes an indispensible component of designing IT supported solutions.

The algorithm of resolving inventive problems (*ałgoritm rieszenija izobratielskich zadacz*)—ARIZ developed within the TRIZ method is dedicated to solving complex inventive problems. In particular, it is meant to be used for designing and analysing complex objects and resolving complicated engineering problems [15]. As a rule all these elements emerge in IT projects—the complexity of modelled business processes plus difficulties of software and hardware technical problems.

The place TRIZ occupies in creative process methodologies is well illustrated by Fig. 2.

The TRIZ theory focuses on the capability of systematic problem solving. Its objective is to support innovative inventions largely based on technical or technical and economic foundations. It combines the tools and methods for an analytical and rational approach. TRIZ flexibility shows in different variants evolving within its framework—engineering, management, science, pedagogy—proving the usability of the method across a variety of distant disciplines [17].

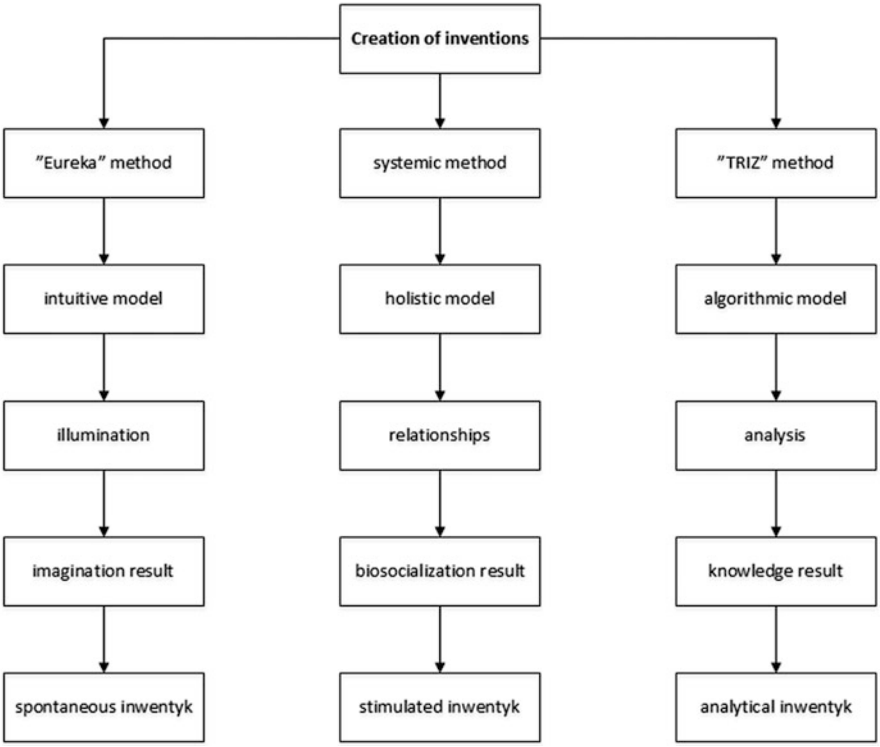

Fig. 2 Classification of invention creation methods [16]

4 How can IT Projects Benefit from TRIZ?

There are numerous tensions and discrepancies in how an information system is perceived. Almost all IT systems entail a contradiction between the need for strict regulations resulting from the nature of business processes involved (technical, legal and security issues, among others) and the need for the flexibility of the system catering for different groups of its users. Being a method particularly dedicated to reconciling competing interests, TRIZ can eliminate or mitigate these critical tensions.

The level of project management maturity in an organisation is a crucial factor of IT projects. The author's research work shows that the lower the maturity level, the greater the expectation that the IT project implementation will cure some vaguely specified business issues. TRIZ appear to address this problem. Applying the so-called TRIZ test to business process will reveal any inconsistencies in the company prior to launching the IT project planned. To analyse consistency of processes, justify the participation of particular components in the process and introduce improvements, different tools can be used in isolation or in combination within a

TRIZ test. At the same time, this approach also establishes common ground for dialogue between a business client and IT, making the client increasingly aware how process improvements should be effected.

For the IT area, TRIZ can play a preventive role, protecting it against IT systems merely copying the already existing business processes. It also protects against those IT solutions which do not contribute anything to the process. What is more, the TRIZ methodology does not allow the creation of unnecessary system components (according to TRIZ, an element which does not generate a function cannot be considered a system component). Thus one avoids an unjustified surplus of components and 'artificial' functions in the system—common phenomena emerging as a very low rate of utilisation of IT system functionalities. Due to the problem solving systematisation it ensures, the method can also prevent confusion of (non-IT) business requirements with systemic (IT-related) ones, a problem IT analysts often complain about.

Another important issue in IT projects is that of placing considerable emphasis on the modelling of solutions, while marginalising the modelling of problems. This leads to a paradox—one attempts to solve, for instance, organisational issues with unsuitable IT measures. It cannot be blamed on improper practices only, as the focus of IT project management methodologies is also mainly on the correct application of particular measures. On the contrary, TRIZ starts with a proper modelling of the problem. In this way, the method makes it possible to make informed decisions about the right order of actions within IT projects and about their priorities.

5 TRIZ and the Project Team

In any IT project involving representatives of the organisation (the client) benefitting from the project, different cultures and professional identities clash. In this kind of context, it is only natural that tensions, communication misunderstandings and conflicts between the client and the IT team occur. Very often the control over the IT system production process is taken over and the decision making borders are crossed by unauthorised IT personnel, which is often harmful to the project outcomes.

The use of TRIZ in IT projects as a common metalanguage has the potential of creating a partnership between the client and the IT team. The changes to be introduced on the basis of TRIZ, following the logic of systematic problem solving, should be agreed on and modelled by both parties involved. The client will find it easier to accept the changes resulting from a mutual agreement. Mitigating or eradicating resistance against changes, which is natural for any IT project, will, therefore, be an additional benefit.

The breaking of a strong organisation culture of IT teams would be another change favourable to IT projects. This could be attained by means of introducing TRIZ or its elements to IT projects. Learning a new language and a new way of thinking offered by TRIZ would shake the IT team out of the tendency to move too quickly from the client's needs to thinking about the IT system itself (or straight to the implementation). TRIZ can successfully provoke the IT milieu to stop, create a space for dialogue and think along common lines rather than deepen the gap between its own and the client's perspective, as has often been the case so far.

A few diagrams below (Fig. 3) present a few ideas on how to apply TRIZ in the setting of IT project teams. Each diagram should be scaled according to particular

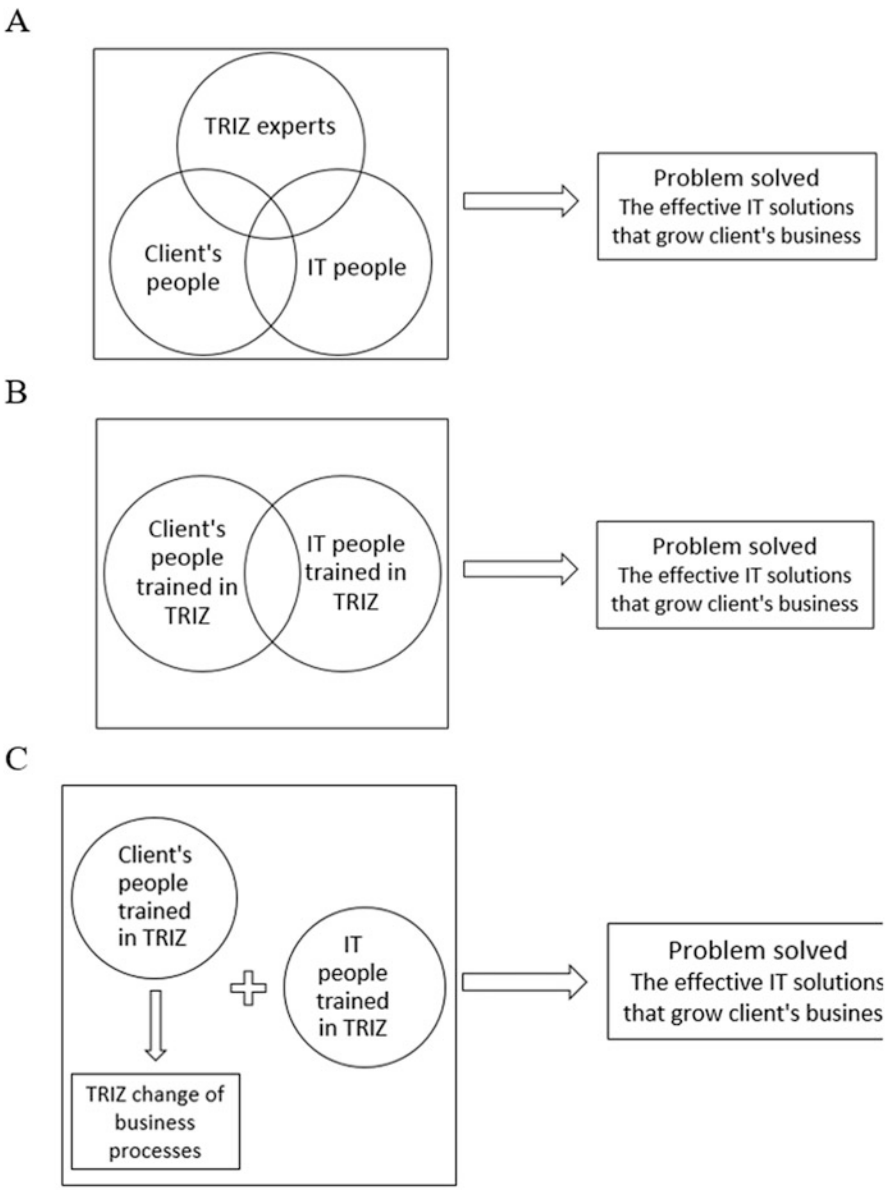

Fig. 3 Diagrams of applying TRIZ in the setting of IT project teams. Source: own

aspects and their combination (size of the organisation, size/complexity of the IT project, IT project implementation methodology, project experience of the organisation and of its IT team, organisation project maturity).

One should also consider a division within the IT department into who should speak the TRIZ language and who does not have to do it. The division can reflect the role played by a given IT team member within the project or be based on the size of the IT company running the projects [12].

6 TRIZ-Based IT Project

TRIZ can be an encouragement to change the perception of the IT system implemented within projects aiming at providing software services commissioned by the client. Fig. 4 depicts a TRIZ-based diagram of IT project implementation. The

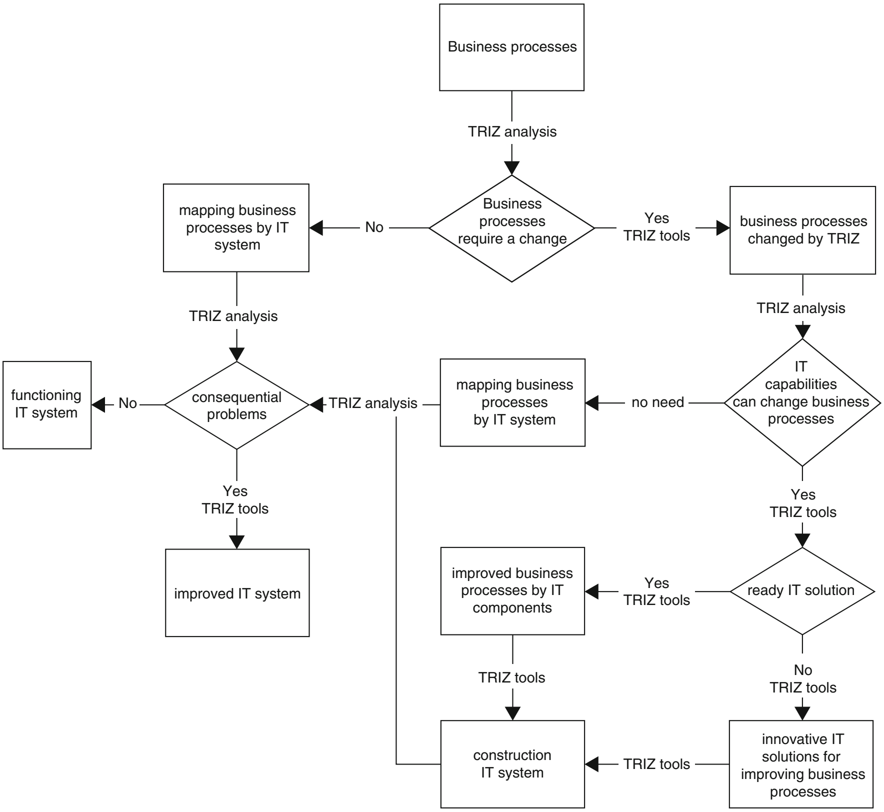

Fig. 4 TRIZ-based diagram of IT project implementation. Source: own

diagram was developed in compliance with the fundamental TRIZ rule, i.e. striving to attain the ideal final result. The most important features of this solutions comprise:

- eliminating the flaws of the current (actual) state,
- preserving the advantages of the current state,
- introducing simple solutions,
- introducing no new flaws.

TRIZ naturally fits the IT projects whose objective is to create dedicated information systems for a particular organisation. This is due to the fact that TRIZ and the projects share the same overall goal: "making a technology available that would enable creating such technical systems that, with lowest investment possible, would ensure best possible realisation of the functions" [18].

7 Implications for Further Research

TRIZ imposes a natural order onto the process of identifying the actual problem and of moving from the problem to the solution. In IT projects, it can ensure a proper order and integrity of the client's (organisation's) needs and the IT project products. TRIZ stimulates taking into account the often neglected need for preparing (modifying) business process prior to the implementation of IT projects thus increasing the chances of increased efficiency of the IT projects.

The idea of combining the scholarly realm of IT project management with systematic methods offered by TRIZ should gradually lead to the creation of IT TRIZ. To attain this, further studies should be conducted towards adapting the rules of TRIZ to both the IT project management and the creation and implementation of IT products. TRIZ methods are to be combined properly with the IT project management methodologies applied. Innovative rules largely pertaining to engineering disciplines should be interpreted in such a way that a decision can be made whether they are applicable to business processes and IT systems. In certain cases, such a transposition of the rules onto the IT project management domain can prove rather challenging and require some research work. While 40 inventive rules for software have been formulated [19] alongside the rules of innovative project management [20], no such aids have been developed for IT projects, which are marked with their own specificity.

It would also be worthwhile to propose guidelines for the implementation of ARIZ for IT projects. ARIZ contains a whole range of procedures. A complete ARIZ will surely be useful for big IT projects, whose outcome is complex systems or IT solutions. With less complex IT solutions, one would have to specify, which components of ARIZ are to be dedicated for a particular type of IT project.

IT TRIZ turns TRIZ into a chance to improve the effectiveness of IT projects, using it as a path on which the TRIZ tools bring together an IT system and a change of business process for the enhanced functioning of the organisation.

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TRIZ/CrePS Approach to the Social Problems of Poverty: 'Liberty vs. Love' Is Found the Principal Contradiction of the Human Culture

Toru Nakagawa

1 Introduction

This is the first report of applying the TRIZ/CrePS methodology to real social problems.

TRIZ (Theory of Inventive Problem Solving) [1] has been established as a methodology of problem solving/task achieving principally in the field of technologies and has been applied in technologies and gradually extending in business/marketing fields, etc. There are many other individual methods, e.g., Six-Sigma, TOC, Lean, etc., known for creative problem solving in such industrial use [2].

CrePS (General Methodology of Creative Problem Solving) [3] has been proposed by the present author as a generalized methodology of creative problem solving which can integrate TRIZ and many other methods by use of a new paradigm, the Six-Box Scheme [4]. The new paradigm is defined in a data-flow representation requesting the information to be obtained in the 6 boxes (along the process). They are:

- Box 1: User's specific problem situations
- Box 2: Well-defined user's specific problem
- Box 3: (A) Understanding of the present system and (B) understanding of the ideal system
- Box 4: Ideas for a new system
- Box 5: Conceptual solutions
- Box 6: Implemented solutions (user's specific solutions)

It should be noted that the initial problem-definition phases (Box 1 and Box 2) and the final solution-implementation phases (Box 5 and Box 6) belong to the Real World (prevailed by society, business, technologies, etc.) while the intermediate

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problem-solving phases (Box 2, Box 3, Box 4, and Box 5) belong to the Thinking World (prevailed by the CrePS methodology and the subject-matter knowledge). CrePS methodology has simple and effective instructions how to proceed, especially from Box 2 through Box 5, and has rich know-how and a system of techniques reorganized/unified from TRIZ and other methods.

CrePS should be applicable wherever problems exist to be solved. Thus, it is expected to be applied in much wider areas, not only industrial and business fields but also at home, education, advanced research, various social activities, national policies, social problems, etc. Thus in the present study I have decided to extend the CrePS application to the field of social problems, where we have so many important issues.

Social problems, however, are often much more complex and big than technical ones. Since I am just a novice in the field of social problems, how can I make any meaningful contribution to solving social problems?

I noticed the 'Fuda-Yose Tool' software developed by Akihiro Katahira, which supports drawing diagrams, similar to affinity diagrams, showing logics of arguments/documents [5]. I have found it nicely fit with my need to clarify the logics/mechanisms of social problems.

Initially I chose the problem of poverty of the elderly people in Japan. I used a newly published book "The Low-living Elderly (LLE)" written by Takanori Fujita, a young social worker, as the source reference [6]. And I visualized the logic of the book in Fuda-Yose diagrams [7]. I learned about the problem in various aspects, especially that poverty is proceeding in Japanese society not only in the elderly, but also in middle-aged, young, and children generations. Thus LLE is a part of the problem of 'poverty in the Japanese Society', which is also just an aspect of much larger problem of Japanese society including its economy and politics.

Another valuable information was that many readers of the LLE book evaluated it highly but many others very poorly, saying "The LLE people themselves, not the society, are to be blamed for falling into such a poor situation" [8]. It is an argument coming from different positions of social philosophy and social ethics.

Considering the root of such different positions, I have found the conflict between two social philosophy, i.e., 'Liberty, Competition, Win-or-Lose' on one side and 'Mutual aid, Help, Collaboration, and Love' on the other side. These are two important targets/slogans in our society, but they are conflicting in the attitude to the practical problems such as welfare policies for LLE. This conflict (=contradiction) is formulated as follows [9]:

(a) Liberty is taken as the First Principle of Human Culture.
(b) Love is taken as the Second Principle of Human Culture.
(c) 'Liberty vs. Love' is the Principal Contradiction inherent in the Human Culture.
(d) Human Culture has been trying to solve the Principal Contradiction 'Liberty vs. Love' throughout its history.
(e) The Contradiction 'Liberty vs. Love' exists everywhere and has become even more complex and difficult to solve in some aspects.

The present study has been guided by the TRIZ philosophy of Contradiction and the CrePS process of problem solving. The Principal Contradiction 'Liberty vs. Love' is going to be revealed further in its basic structure, mechanisms, cases, etc. in future.

2 Visualization of the Problem Situations

At the start of applying the TRIZ/CrePS methodology to social problems, we need to find a problem and recognize the problem situations. Since there are many problems to be solved in our society, finding a problem actually means to select a significant problem which has big influences on the current and future society and is demanded to solve or improve. In the present super-aged society in Japan, I have chosen the problem of poverty among the elderly people. Behind the wealthy appearance of Japanese society, poverty is spreading increasingly widely in various generations.

For recognizing the problem situations, I was lucky to find a good reference, a newly published book, "The Low-living Elderly (LLE)" written by Takanori Fujita [6]. On the basis of author's activities with an NPO for supporting the needy people, the author describes the current situations of the low-living elderly, how they fall into such LLE situations, the present welfare system in Japan, etc. He is alarming that most of the middle-aged and young people have high risks of falling into the LLE state in their future elderly days and suggesting a set of proposals of new welfare policies.

Books are good for reading. But it is not easy for a reader to introduce the essence of the book to other non-reader people and for a group of people (readers and non-readers) to discuss on the topic. For such purposes of communication, visualized diagrams are often more useful than sentences. Fuda-Yose Tool developed by Akihiro Katahira [5] is useful for me to visualize the full logic of the LLE book. The visualized diagrams have been posted chapter by chapter in "TRIZ Home Page in Japan", and were made into a pamphlet of 24 pages [7].

Figure 1 shows the visualized diagram of the Introduction section of the LLE book. The texts of eight pages were processed in the following way for the visualization:

- I read the whole book closely twice and decided to visualize the book.
- Reading the texts repeatedly I made excerpts/summary for each paragraph.
- Excerpt sentences are converted into the Labels (i.e., rectangles) on a Excel sheet in the Fuda-Yose Tool.
- The Labels are arranged so as to clarify the logic and structure of the contents.
- Groups of Labels are enclosed with rounded-corner rectangles (i.e., Enclosures) and relationships between Labels (and Enclosures) are shown explicitly with Lines/Arrows.
- The diagram is finalized by neglecting unnecessary details and adding complementary notes, etc.
- Simplifying the whole diagram is often necessary for clearer and easier presentation to people.

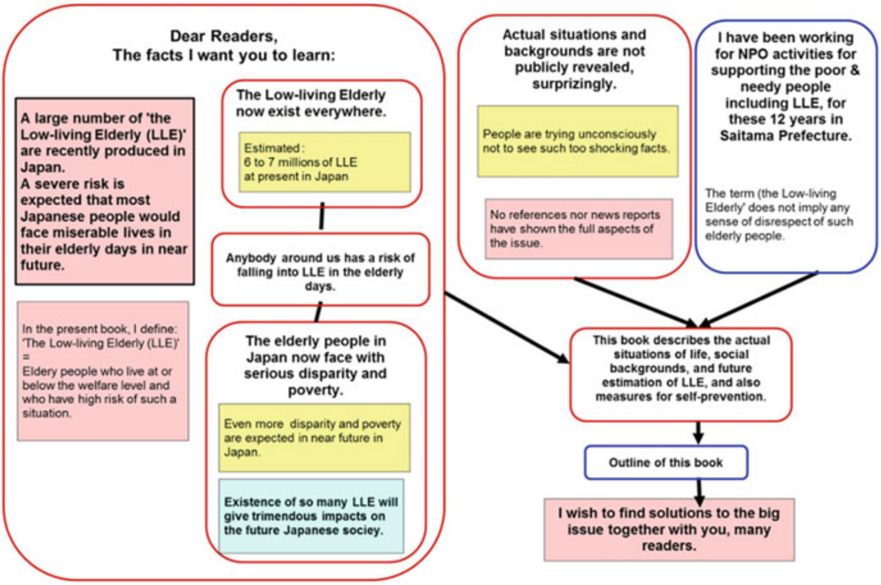

Fig. 1 Visualized diagram [7] of the Introduction section of Fujita's "The Low-living Elderly" book [6]

In this manner the diagrams like Fig. 1, can convey the author's thoughts/intentions clearly to people who have not read the book yet. Diagrams can show the overall macro structure as well as the detailed micro relationships of information. This feature is particularly useful for discussing the issue from different aspects.

3 Focus of the Problem

3.1 Future Risks for Many People to Fall into the LLE State

The visualized diagrams have revealed a number of important issues to be discussed to solve. One of them is the future high risks for the current middle-aged and young generations to fall into the LLE state in their future elderly days. Fig. 2 illustrates this issue (Chap. 3 of Fujita's book). Even though many Japanese people do not realize the risks, the effects of the super-aged society are already clear in various social and economic problems and are getting more and more severe in the future, in 20–50 years.

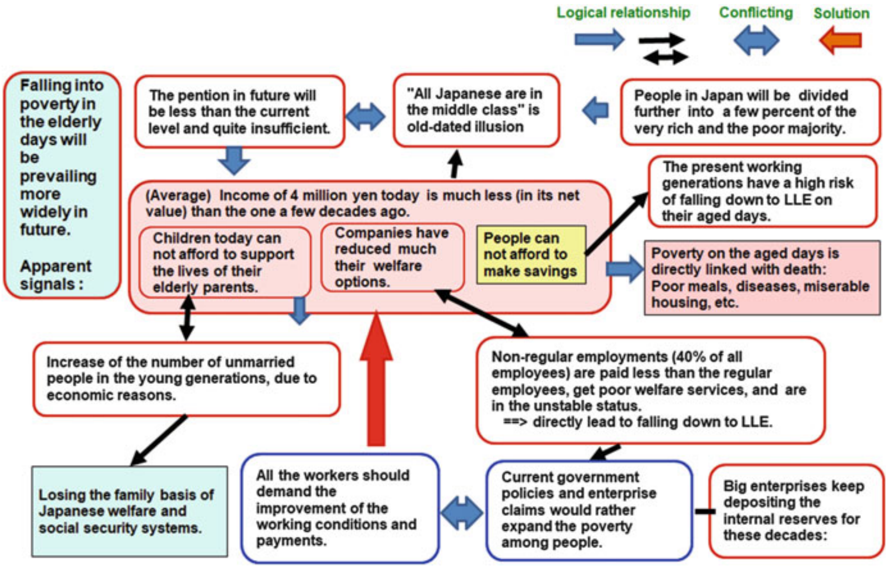

Fig. 2 Visualized diagram: (3B) Anybody has a risk of falling into the LLE status (in the near future) [7]

The author points out the following big factors:

- The pension in future will be less than the current level and quite insufficient.
- Family (or children) today will not be able to afford to support the lives of their elderly parents.
- The income of the present working generations is reducing in average. Especially, non-regular employees are increasing much in the percentage and they suffer from unstable employment and very low income.
- The welfare level provided by the companies have been much reduced nowadays.
- The savings by the present working generations are not enough for their elderly lives.
- Current government policies and big enterprises motions are increasing the disparity of wealth in the Japanese society and producing more LLE people now and in future.

In these situations, the author writes that demands from the workers standpoints should be raised to solve this poverty problem. This is certainly an important issue.

There are many other similar issues of practical importance. But they are put aside at moment because the issue described in the following Sect. 3.2 is found most fundamental and important as the focal issue of the present study.

3.2 Unsolved Problem Underlying People's Feelings

The LLE book has become a bestseller in Japan and 82 customer reviews were contributed to the Amazon.co.jp site. I was rather surprised to find that even though many reviewers evaluated this book highly, many others evaluated very poorly and quite a few readers show sympathies with such low-evaluations. I critically reviewed all the 82 customer reviews and wrote my own book review [8].

The author explains that the LLE people are produced by the society system in spite of their own efforts. The low-evaluators claim that the LLE people themselves should be blamed instead of the society. The author writes in the book that he received similar criticisms on his NPO activities for supporting the needy and poor people.

These arguments are discussed in Chap. 4 of the book, as shown in the diagram in Fig. 3 [7]. The Enclosures in Fig. 3 represent different standpoints.

Unfortunately the arguments here show a typical mismatch. The people in the left column talks on their feelings directly, while the author in the right column talks logically on the basis of his recognition of the society. Thus the LLE in the middle column seem not be released in their feelings.

Thinking over the roots of these arguments, I recognized that the two sides have their roots in different but important social philosophy, respectively, as shown in Fig. 4. The left hand people are talking on their mentality deeply imprinted 'to Win' in the competitive society, with the slogan of Liberty. The right hand people represent the philosophy of mutual help and welfare, with the slogan of Love.

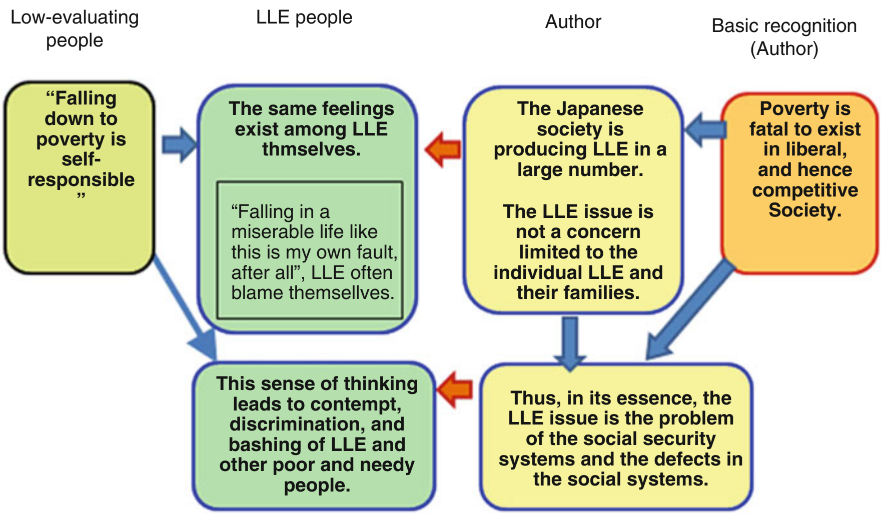

Fig. 3 Visualized diagram: Is LLE self-responsible? or produced by the society? [7]

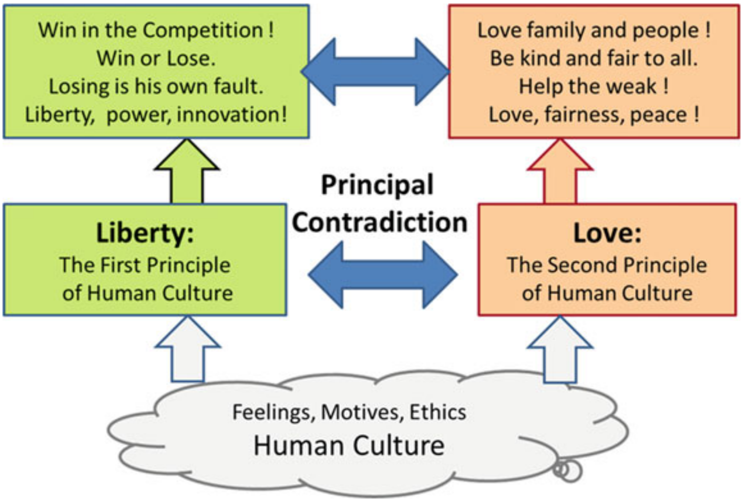

Fig. 4 Roots of the people's arguments at the social philosophy level

4 Understanding the Present System

The viewpoint shown in Sect. 3.2 is so fundamental that I have decided to focus on it first. Reflecting on the issue, I have proposed the following concept [9]:

4.1 'Liberty vs. Love' Is the Principal Contradiction Inherent in the Human Culture

(1) **The Human Culture takes Liberty as its First Principle** and pursues for extending it. Liberty is for every person to decide, to act, and to live for oneself. Liberty aims at Winning various, natural or social, Competitions. Liberty of a person necessarily collides (Contradicts) with Liberty of another person.

(2) **The Human Culture takes Love as its Second Principle** and pursues for spreading it widely. Love is for every person to help and protect one's children, one's family, and one's neighbors. Love aims at Self-controlling one's Liberty and at eliminating collisions among Liberty in one's Family. Love, for helping and protecting the Family (or Insiders), tries to counter the (attacking) actions from Outsiders. Considering the Family (or Insiders) as a social Activity Unit, Love generates Liberty and Competition at a higher social level.

(3) The Human Culture has been extending the two Principal Principles, i.e., Liberty and Love, and has been seeking for how to use these two often-contradictory Principles in compatible and appropriate ways. **'Liberty vs. Love' is named the Principal Contradiction of Human Culture**, in the present paper.

(4) As the guidelines for containing and motivating both Liberty and Love and coordinating them, the Human Culture has been acquiring **Ethics**, i.e., Moral, Conscience, in plain words. The core part of Ethics is supposedly installed already in our DNA; and for the same reason it is too obvious and difficult to write it down clearly. The concept of **Fundamental Human Rights** is a part of Ethics stated clearly.

4.2 Difficulties in Solving the Principal Contradictions

(5) Throughout **the history of Human Culture**, Humans have been trying to extend the two Principal Principles, Liberty and Love, and to resolve the Principal Contradictions between them, i.e., Liberty vs. Love.

In the history of Human Culture, various social organizations and social systems have been built (e.g., economy, politics, etc.) and advanced culture have been generated (e.g., languages, religions, social philosophies, science and technology, arts, etc.)

(6) So our question is: **Has the Principal Contradiction, Liberty vs. Love, been solved through the Human History?** The answer is: **Partly YES**, because some cases (and philosophy) of solutions were obtained. **But mostly NO**, because cases of Principal Contradictions exist everywhere, newly appear everywhere, and become more and more complex, large, severe, and difficult.

(7) **The causes which make the Principal Contradiction even more difficult to solve** are considered as follows:

(a) **At the most basic level of individual person(s)**, actual and desirable relationships among Liberty, Love, and Ethics are not clear yet (in the aspects of reality, intellect, and moral). The issue of Desire/Greed, Evil, and (Fundamental) Sin in the Human Nature is intrinsic. Personal feelings and thoughts are formed/influenced through different experiences since one's birth and throughout the life (in relation to environment, education). People are very often moved by their feelings rather than their intellect.
(b) **For various types/levels of social organizations**, actual and desirable relationships among Liberty, Love, and Ethics are not clear. (e.g., groups, companies, political parties, communities, countries, etc.) Understanding of such desirable relationships (i.e. Social Ethics) is not shared globally.
(c) **Individuals and organizations sometimes insist on their Interests (Liberty)**, and act against (Social) Ethics, and can become the Social Winners. Such social Winners re-built the Social Systems in a way favorable for themselves.
(d) **Situations of (c) exist everywhere**, in the scales from tiny to huge, and **are accumulated in many layers in the Human History**. (At any time) Social Systems do not meet the (Social) Ethics in some aspects, and some people who were oppressed raise the action (c) and start the conflicts/fights

5 Summary of the Present Study and Future Tasks

As described so far, the present study has been guided by the process of the CrePS methodology [3, 4]. Fig. 5 illustrates how the present study is proceeding in the Six-Box Scheme.

For the first case study of applying the TRIZ/CrePS methodology to real social problems, the problem of poverty, especially among the elderly, in the Japanese society was chosen. And Fujita's LLE book was used as the reference to learn the problem situations. (Box 1; Sect. 2).

For the purpose of finding the focus issue of the problem, the logic of the LLE book was fully visualized in Fuda-Yose diagrams and customer reviews on the LLE book were critically reviewed. Underlying the arguments by ordinary people I have found an important conflict in their understanding of social philosophy, as shown in Fig. 4. (Box 2; Sect. 3).

The conflict was understood by the present study in a formal theory, i.e., 'Liberty vs. Love' as the Principal Contradiction of Human Culture. Factors which make the Principal Contradiction even more difficult to solve were considered. (Box 3A; Sect. 4).

For the future task, the understanding of the Principal Contradiction 'Liberty vs. Love' should be deepened in relation to the factors of (a) to (d) in Sect. 4.2. This will be a big task, of course, because we are going to study the Principal Contradiction inherent in the Human Culture.

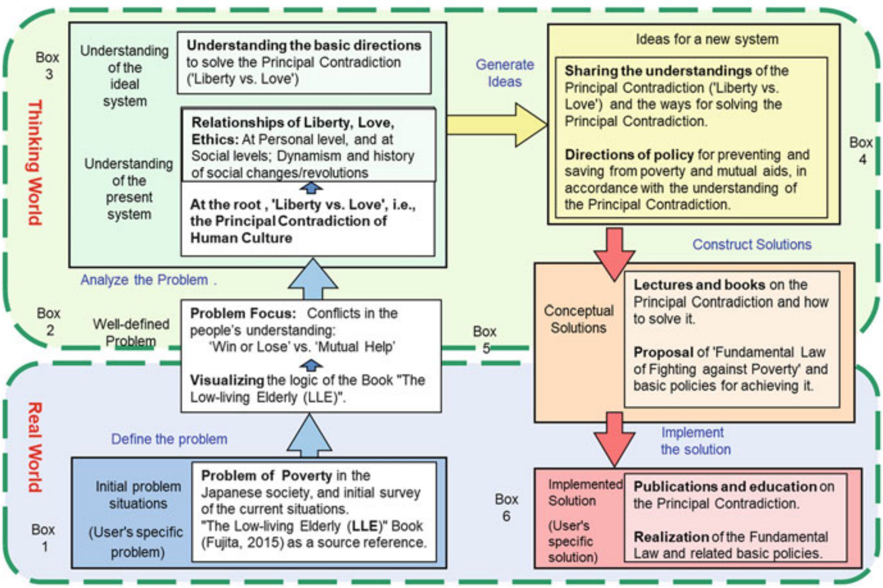

Fig. 5 The present study and its future summarized in the Six-Box Scheme of the CrePS methodology

Box 3B advises us to understand the ideal system of the present issue, i.e., the ideal situations where the Liberty and Love coexist in harmony. Such ideal situations should be considered not only in an abstract conceptual way but also in some more realistic situations with respect to the factors (a) to (d).

Box 4 requests us ideas for a new system. In the present study, they will mean sharing the understanding of the Principal Contradiction 'Liberty vs. Love' and the understanding of the ways of solving it. And also such understanding should be applied to the problem of poverty.

Such two directions of solution ideas, one theoretical and the other practical, should be followed in Box 5 and in Box 6, as shown in Fig. 5.

It is remarkable that the TRIZ philosophy of Contradiction underlies the present research: To recognize and reveal the contradiction in the core of the problem, and to solve the contradiction!

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Product Development Using Heuristic-Systematic Approach: A Case Study

Bartosz Pryda and Marek Mysior

1 Introduction

This paper is a summary of a case study conducted during design class. The task was to design a new product or to modify the existing one for it to be attractive on the market. We decided to limit our study to design a garden table, because it has low system complexity and is well known to most people in the world. Starting the design, it was very important to decide upon selection of a proper design methodology that will provide the most innovative product. There are many approaches in machine design that are being used depending on the type of designed object [1–3]. For the design process to be effective, it is very important to take into account changes in requirements defined by customers in time [4]. One of the considered approach is to re-design the mechanical object to make unanimous as many customer requirements as possible. Achieving this goal may be fulfilled by the use of Theory of Inventive Problem Solving (TRIZ) [5] with the application of Failure Mode and Effects Analysis (FMEA) [6]. Those methodologies are referred to as **systematic methods**, since they provide step-by-step approach in product design. As the opposite one may distinguish **heuristic methods** that are based on the assumption that human development of new ideas (design concepts in our case) requires knowledge and is inspired by knowledge from various domains [7]. An example of purely heuristic method in product development is Synectics [7] or Brainstorming. There are also other methods that combine step-by-step approach with heuristic knowledge acquisition, like Design Thinking [8] or modified Synectics [7] that not only take into account product development as such, but also deal with market research and problem formulation both in the context of cause and effect.

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Creation of technical objects is a result of specific needs and possibilities of their fulfillment, thus at the beginning of a design process it is necessary to define the need and to plan on how to satisfy it. At this moment it is necessary to set a compromise between the quality of the product and the cost of its creation [1]. In the presented case study, **the need authors chose for fulfillment was a need of having a table, used specifically in gardens, that is possible to be manufactured using the simplest materials possible in the simplest possible way.** In this work, authors have employed two approaches to machine design. First one is based on conventional approach proposed by [1] in which the object to be designed has to be as simple as possible (reduction of costs) and has to satisfy basic needs only. Second approach was a case study of an original heuristic-systematic method developed by authors that allow combination of heuristic and systematic tools in product development, based mostly on TRIZ and Synectics and taking into consideration design requirements throughout the design process.

2 Design Using Conventional Approach

Design process leads to creation of new technical objects. One of the fundamental principles of design is that the need for a design comes directly from the need of a customer [1]. The result of design is a solution that satisfied those needs—either current or future needs. To design the right solution, those needs shall be described as precise as possible. Those needs shall be then confronted with capabilities. Limited capabilities may impair implementation of a desired solution that fulfills customers' needs in the best possible way, which leads to a compromise between capabilities and fulfilling needs. A general scheme of conventional design approach was presented in Fig. 1.

The process starts from identifying the needs of customers. These needs are identified with various methods depending on the branch, scale of operation and other factors. Some of the most common methods are customer data mining or customer satisfaction forms [9]. Those needs are then confronted with capabilities. Some of them are: financial limitations, technological limitations, market or law regulations, competitors. The result is a compromise between needs and capabilities. It is later translated into more precise design tasks for designers or design engineers. As a result, a model is created. Model is then studied in terms of its final approval. A solution is finally implemented and the need becomes satisfied. An example can be the need for faster and more cost-effective design process that was satisfied with creation of CAD/CAM/CAE computer software.

A test of a conventional design procedure was performed for a garden table. At first, a need was defined. According to a given requirement in the case study, a table needed to be cheap for the customer. In order to fulfill that requirement, it was confronted with a potential table manufacturer capability. To ensure low price for the customer, a product should be simple in terms of number of components and their manufacturing technology. The resulting requirements were presented in a Table 1.

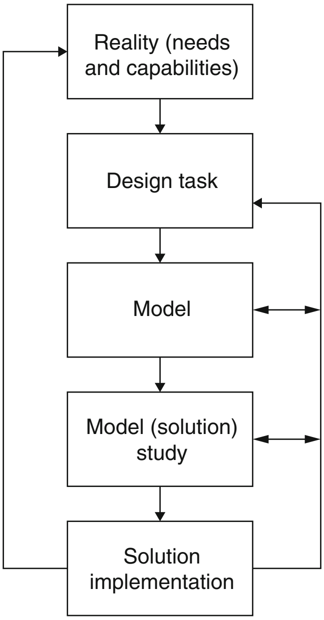

Fig. 1 Scheme of simplified conventional design process, based on [1]

Table 1 Requirements defined using conventional approach

Requirement 1	Low price
Requirement 2	Simple design

Fig. 2 Isometric view on a garden table designed using conventional approach

Then, a concept design was created using these requirements. A result is shown on Fig. 2. a proposed garden table represents a well-known design that serves a primary function (holds goods in horizontal position) and fulfills necessary requirements (cheap, simple).

3 Design Using Heuristic-Systematic Approach

The design strategy presented in the previous subchapter can be summarized by three steps and is presented on Fig. 3. At the beginning of the process, there was a need to be satisfied, the need of having a garden table. This was an input to the design process, that was performed under set of constraints and requirements. The result of the whole process was a design of a garden table presented in the previous subchapter.

The conventional approach does not concentrate on variable aspect of needs in time as well as the reason for requirements that should be satisfied. The outcome of the design using this method was very similar to already known solutions on the market, which may result in very high risk of commercialization due to competition from existing producers and companies. To overcome those difficulties, another approach in design was employed that included deep analysis of customers' needs, their evolution and employed some amount of heuristic thinking to produce the final concept. The approach was based mostly on the method proposed in the article [7], with several new aspects included, mainly the use of TRIZ. The new approach comprises of several steps in which specific needs are translated into problems, both in the context of the cause and effect. Those problems are then translated into contradictions, that are being the base for heuristic concept evolution based on Synectics. The algorithm of the method is presented on the Fig. 4.

As a part of problem identification, specific needs and requirements are translated into problems that are critical for the quality of a design, as presented in [10]. Not only are those needs and requirements analyzed in the context of quality, but also in terms of technological, economical, ecological and social barriers and drivers that

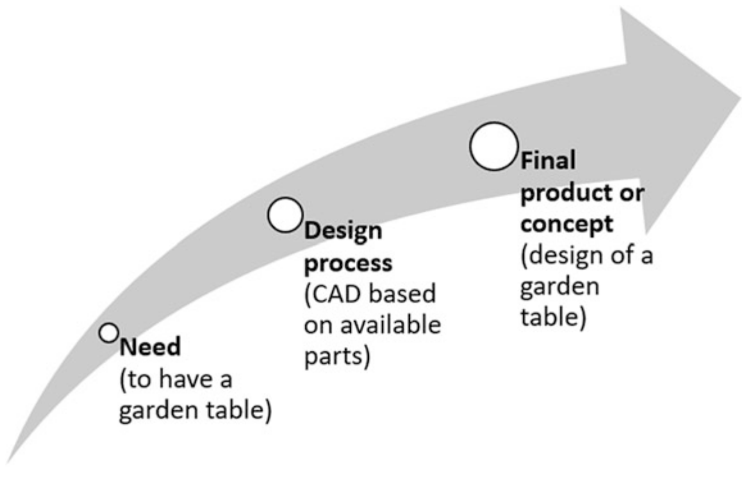

Fig. 3 Scheme of the conventional design process employed in the article

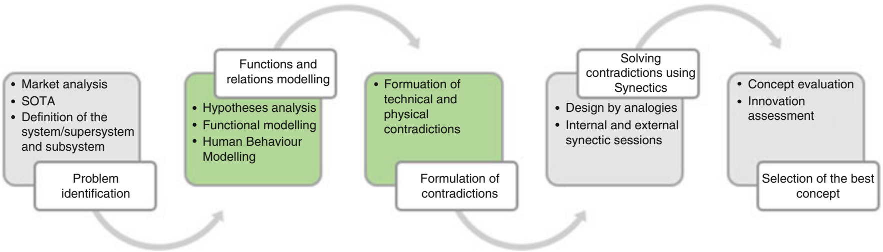

Fig. 4 Scheme of the proposed heuristic-systematic approach in product design. Based on [7]. Areas where TRIZ can be implemented are presented in green

affect technology development. State of The Art (SOTA) analysis makes it possible to identify the market size and competing technologies/solutions. Based on research, it is also necessary to specify the supersystem (environment in which system operates) and subsystem (components and resources a system uses) that will be important in terms of further work.

Functions and relations modelling allows to identify physical phenomena and parametric relations between the components of the system as presented in the book [11] on an example of Mobile Biogas. Based on identified supersystem, subsystem and function realized by the system and its outcome, it is possible to define basic relations in terms of physical parameters that can be described in terms of quality and can be also translated into contradictions.

Contradictions are one of the fundamental tools of TRIZ. In the proposed approach, contradictions are formulated based on physical parameters describing particular concept in development, and are then being solved using heuristic thinking implemented based on Synectics [7]. The final stage of the proposed design process is the concept evaluation, that takes into account innovation assessment and evaluation based on assumed design criteria, such as presented in [1].

4 Problem Identification

At the beginning of the process it was important to define the system that our problem represents and establish the relationship with other systems. A system here can be defined as a combination of parts that interact with each other and together create some new value [12]. Systems are contained in super-systems and are dependent upon them. Systems consist of sub-systems that combined create a system. A properly defined system helps to focus on and understand what exactly the system is and what are its relation between other systems, super-system and sub-system. An example of a system can be a car. Its sub-system would be, for example, an engine. Its supersystem could be an infrastructure: roads, oil industry. The system in this case study was a garden table. Its super-system was a garden in a house. Its sub-systems were: countertop, frame.

After system-definition a system was understood well as well as the relations. Market analysis was performed to understand the way customers see garden table and its super-system. Market analysis was performed with two approaches: heuristic (empathy map) and systematic (customer data mining).

Google trends and statistics analysis were the tools used for data mining. Thanks to trend analysis the authors were able to define areas with higher interest in buying a garden table (Fig. 5), and which is the most common time of a year to buy a garden table. Number of searches for a garden table was the highest in Greater Poland. People tend to buy tables in the spring and summer time. Also, similar searches that are becoming more popular were suggested (Fig. 6). These phrases included "wooden garden table" and "wooden plastic table" which is an important information regarding materials that commonly bought tables are made of.

Another step to identify the market situation and possible problems was state of the art analysis. A system was investigated in the range of used technologies, suppliers, raw materials, companies, patent search and literature analysis.

Empathy map is one of the tools used in Design Thinking. Design thinking was created to better understand the target group [13]. Empathy map chart is divided into fields that a designer should fill out upon discussion with a customer. Those fields are divided into categories that consider different aspects of customers'

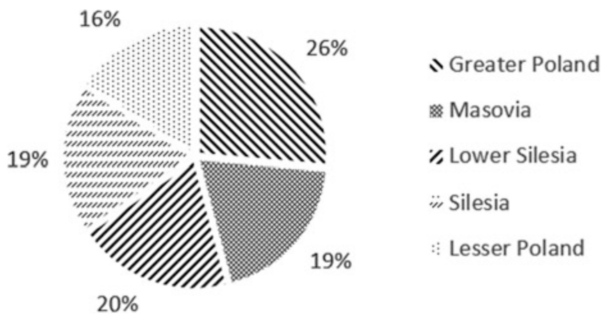

Fig. 5 Interest in buying a garden table by voivodeships. Own elaboration based on Google trends

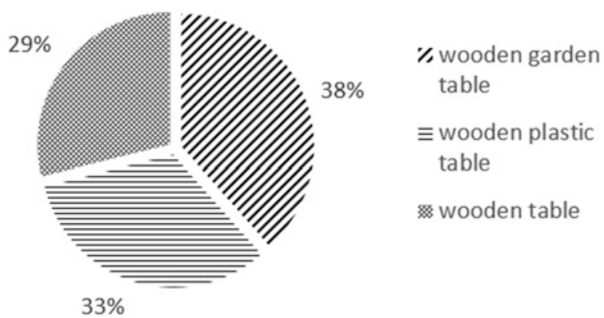

Fig. 6 Similar searches to phrase "garden table" and it's popularity. Own elaboration based on Google trends

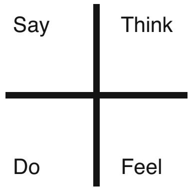

Fig. 7 Chosen empathy map canvas

Table 2 Selected elements of empathy map

Say	Think
– Modern tables are not well manufactured or bad materials are used – It should be protected from bad weather conditions – Tabletop should be removable – It should be easy to be stored without any tools as well – Water accumulates on the table top – A table should be wooden	– Modern goods are not good in terms of a quality – Acceptance of the owned table – Stability and comfort are the most important things
Do	**Feel**
– They do not store it at all – They buy plastic tables – They buy heavy, non-flat table	– Happy with owned solution (while having table stored in a garden house) – Not happy with offered garden tables (while not storing a table)

behavior, their answers and designer's thoughts. From different variations of empathy map canvases, the chosen version (Fig. 7) consists of four fields:

1. **Say—**quotes said by the customers/stakeholders; direct questions like: 'do you like the product?', 'What would you like to improve?', 'What do you need?'
2. **Do**—observed behavior. How does a user use the product? How does he/she overcome obstacles (own improvements)?
3. **Think**—probable thoughts. What is user motivation? What does he care most about? How does he want to use a product?
4. **Feel**—definition of emotions. Does the user look happy? Is he/she irritated by doing something?

The results of the empathy map interview were collected. Selected elements are presented in Table 2.

The results of the Initial problem was formulated in the context of Technology, Economy, Environment and Society (TEES) based on Empathy Map that was created on the survey with ten people. People were asked how they use their garden tables and when do they do it, what do they do with it and which features are important for them. Their responses were collected and organized them in the form of empathy map in the groups of what they say, think, feel and do. Repeating quotes and most desire features were selected and assigned to respective TEES category. These features were defined as the most important features of a table for the interviewed group (Table 3).

Table 3 Desired parameters of the garden table in the context of TEES

	Technology	Economy	Environment	Society
Features	Need of storing	Low price	Protection from weather	Leg room
	Flat surface	High durability	Eco materials	Pleasant look

5 Relations Modeling with Contradiction Formulation

In selected case study, only relations modelling was done. Relations modelling was performed using hypotheses analysis. This approach, proposed by [11], makes it possible to identify physical relations between the system, its supersystem and subsystem and describe them by the use of physical parameters. The analyzed system was defined as the garden table, being in a strong relationship with the user. The super-system was defined as a garden and the subsystem as wood (the table had to be wooden based on customers' demand). The main function of the garden table was defined as celebration. Map of hypotheses and selected relations between elements is presented on the Fig. 8.

Based on the hypotheses analysis it was defined, that the following functions are critical for innovativeness of the design concept:

- Fun
- Distribution/serving
- Cooking
- Using

Based on defined functions, the following contradiction was defined.

Technical Contradiction

In the next step, technical contradictions were formulated based on diagram elements and defined relations that are important from the point of view of the innovativeness of the design concept. Words in brackets indicate key phrases for contradiction formation.

A <garden table> should have many possible aspects of <**celebration**> providing **as much** <**fun**> as possible, **without a negative influence on ease of** <**using**>**.**

A <garden table> should have simple <**structure**> to allow ease of <**using**>**,** without a negative influence on possible aspects of <**celebration**>**.**

Physical Contradiction

Technical contradictions were rephrased into physical contradictions, that were base for definition of the inventive task for the heuristic approach.

A <**structure**> of a garden table should be <**complex**> to allow many aspects of celebration, and <**simple**> to maintain ease of <using>.

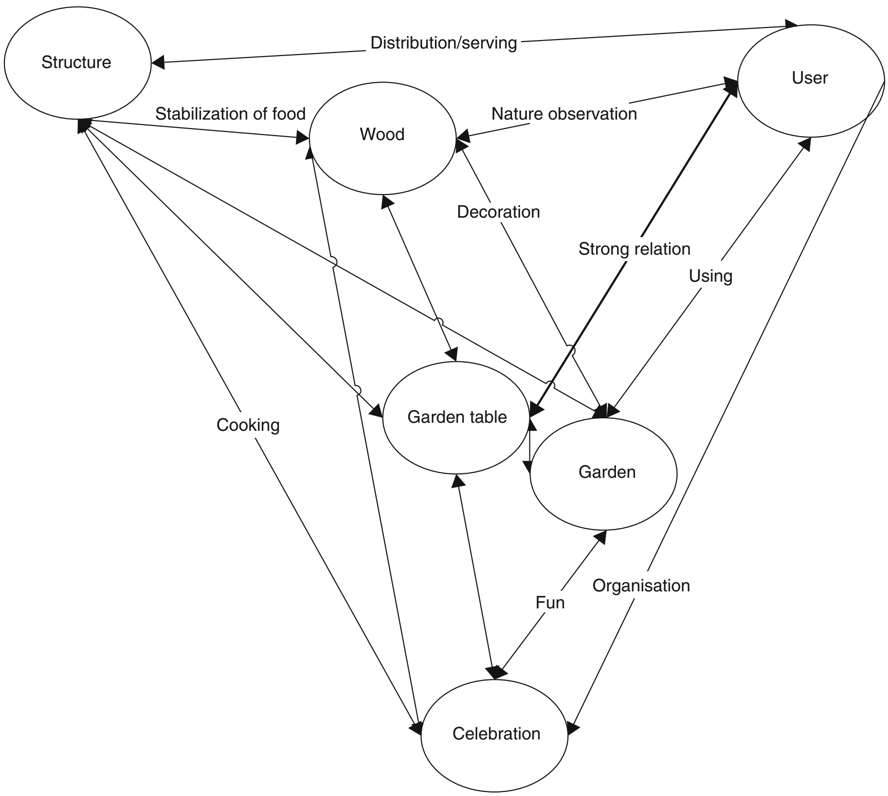

Fig. 8 Hypotheses analysis of the garden table and relations between diagram elements

The above, supplemented with few more contradictions, lead to the innovative task formulation:

> How to design a table, which facilitates serving—provides storage for plates/cutlery and at the same time is related to the nature, lets us keep food warm/cold on it and gives extra cooling space for our favorite drink?

The above inventive task was subjected to heuristic development using Synectics [7]. As a result, two concepts of innovative garden tables were developed. Each of the two newly designed tables comprised all functions defined as important in function analysis. The first solution, as shown on Fig. 9, makes it possible to store food in the stowable container in the middle of the table and provides stability and ease of transport by means of water ballast. When the table has to be moved to a different location, the ballast can be removed easily with no harm for the environment. This is an example of separation in time principle.

The second solution is more concentrated on fun, using and serving functions and is presented on Fig. 10. Providing the area for food serving, it is very easy and

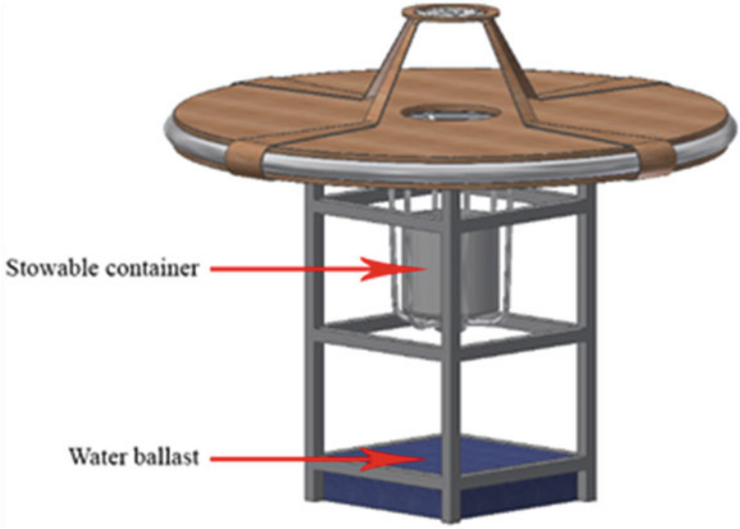

Fig. 9 First design concept developed using heuristic-systematic design process (T1)

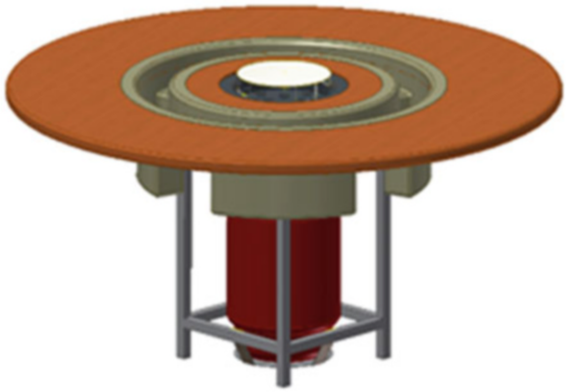

Fig. 10 Second design concept developed using heuristic-systematic design process (T2)

practical to serve dishes that can be easily transferred to each part of the table by means of small boats often seen Sushi restaurants. In the middle part there are gas nozzles and a grill that allows to cook dishes.

6 Comparison of the Two Approaches and Design Concepts

In order to assess a performance of both approaches, a qualitative assessment was performed on the three designs. Designs were assessed against eight requirements that were established using empathy map and collected on the radar chart (Fig. 11).

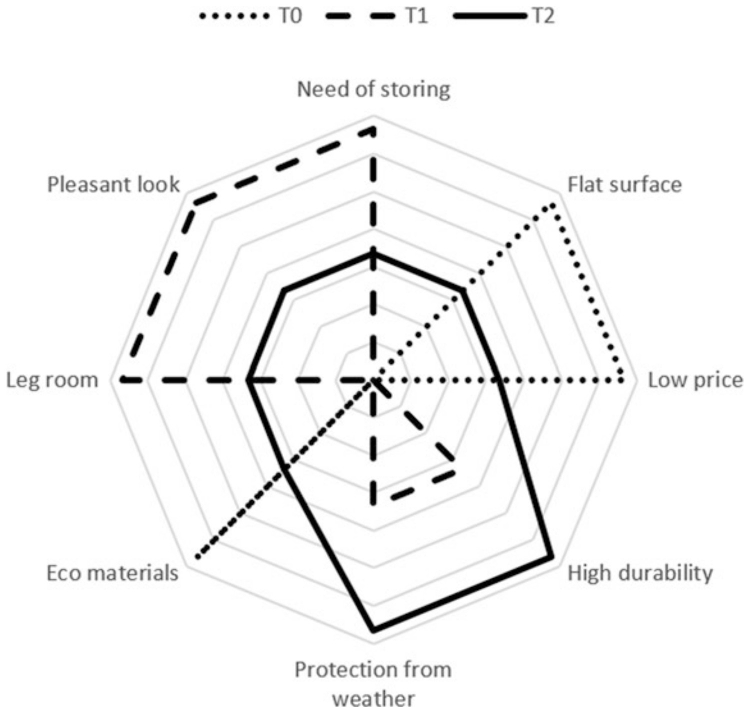

Fig. 11 Results of qualitative assessment of table designs. T0—table designed with conventional approach; T1, T2—tables designed using heuristic-systematic approach

Table 4 Assessment method for fulfilling design criteria

Leg room					
	Iteration 1	Iteration 2	Iteration 3	Sum	Position on scale (0–1)
T0	0	0		0	0.00
T1	1		1	2	0.67
T2		1	0	1	0.33

Each criterion was assessed using a comparative analysis, confronting each pair of solutions. A method of criterion assessment is shown in Table 4.

The results show that the T1 design fulfills its design criteria and also is better than other designs in some categories. However, it does not fulfill all customers' requirements. Designs T1 and T2 fulfill those requirements. "Low price" requirement was neither fulfilled by T1 nor T2 design. The authors presented all solutions to a group of potential customers that was interviewed during empathy map creation. 100% indicated either first or second design concept developed using heuristic-systematic design process as their potential choice when buying a table, neglecting a price factor.

Solutions developed using heuristic-systematic approach were also assessed by a Patent Attorney. Both solutions were filed for a patent at Patent Office of the Republic of Poland (PL P.413935 and PL P.413936).

7 Conclusions

To sum up, application of heuristic-systematic approach in conceptual design results in different solutions than using conventional approach. The main difference in the design process is that proposed heuristic-systematic approach takes into account variable user requirements and needs and provides solutions to their satisfaction by application of TRIZ, Synectics and many other problem-solving and design methodologies. This approach leads to innovative solutions that are patentable and respond to actual needs. In conventional approach, there is no emphasize on market research and customers' needs analysis, thus in proposed approach, true needs are identified in the context of technology, economy, ecology and society to produce new innovative and patentable concepts. At the end of this study, an innovation assessment was performed against all concepts. All solutions satisfied basic needs for such system. However, solutions developed using heuristic-systematic approach featured functions that were not known in the current system or they were fulfilling customers' needs in a new way. The two obtained solutions using heuristic-systematic approach are better looking, provide bigger space for storing things are better protected against environment they work in comparing to the first concept. This has decided on their attractiveness and therefore was the ultimate factor to choose such solution over conventional one.

Different outcome of the design process is a result of different design approach. In conventional approach, designer is not aware of true needs of the customers wherein in proposed approach the problems are first identified, then rephrased and finally addressed in the proper manner producing tangible solutions that are ready to be implemented in real life.

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TRIZ Based Problem Solving of Tile Manufacturing System

Sebastian Koziołek and Mateusz Słupiński

1 Innovative Problem Solving

Solutions that we benefit from in our everyday lives have their origins in problems. Each problem addressed by some approach eventually results in a solution. Depending on what kind of approach one did apply to a problem, the result comes after more or less time and is more or less satisfactory. Therefore it is important to use a tool well suited to case one is going to study.

What is important to notice is that problem exists in a particular setting. What is identified as a problem in one place and at one time may not be considered as a problem in another place and at another time. Consequently, solution to this problem will be viable in these conditions. As the solution is viable in particular situation conditions, it is also limited to these conditions and if conditions change, the solution may not work and it has to change as well. Particular situation conditions are an important factor in decision to select appropriate problem solving tool.

Telling from the reasoning presented above, in order to be well prepared for a problem solving process, it is important to describe particular situation conditions of a problem setting, in short, to describe a problem. There is an interesting relation between problem description and problem solving process. Problem description takes place before problem solving. However, it is also possible to observe that solution to a problem is its best description. From this point of view preparation of problem description moves a problem study towards problem solution. Sometimes a solution is found even before a formal end of the problem description.

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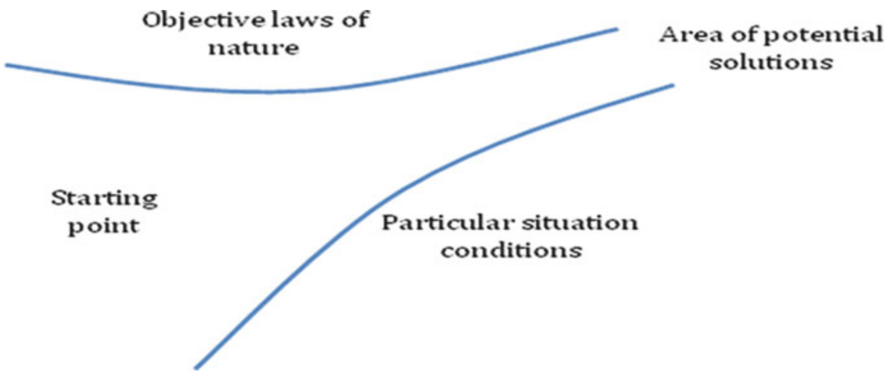

Fig. 1 Area of potential solutions

Let's stop for a while and answer the question what is an objective of the problem description? The objective of a problem description is simply, to narrow down the area where potential solution may be found. The description of particular situation conditions and in general, problem description sets multiple constraints that are to be obeyed by a potential solution.

In TRIZ theory, all possible restrictions that may appear in the space of problem and solution are pictured as two sets of restrictions i.e.: objective laws of nature, particular situation conditions (Fig. 1).

2 Plan of Action

In this paper we would like to focus on the problem description. Our objective is to narrow down the area where a potential solution is located. In order to do that, it is proposed to use a set of tools gathered from the wide range of tools included in TRIZ. The set of tools is assembled for the particular case study. Apart from tools and concepts usually applied to describe a system, some tools, particularly preferred by the authors, are also included and demonstrated. All tools come from TRIZ or its later development OTSM-TRIZ. Other approach to problem description with application of not only TRIZ but other tools is presented in [1]. Some of tools or concepts, which are going to be used in this paper, are included in TRIZ but are common also for other approaches.

From the beginning the idea of application of problem description tool is to narrow down the area of potential solutions. Area to which the reference is made to, is a fictional area of all possible solutions for various conditions. Solutions on the whole area are called partial solutions as they are able to satisfy some requirements leaving other needs out. The initial guidelines on this area are two lines, that we have already mentioned, a line representing the objective laws of nature and other line representing limitations of particular situation conditions (Fig. 1). Problem description process moves through the area of potential solutions setting constraints on the area. This process can be seen also as more and more precise definition of two basic constraints present from the very beginning i.e. objective laws of nature and particular situation conditions.

The plan of application of TRIZ tools for the purpose of problem description is following. First the border of the system will be described. Border of a system has two sides i.e.: system side and outside, and many dimensions e.g. time, space, organization, policy. Then the composition of a system should be described by the means of SFR tool (Substance Field Resources) [2]. Having this knowledge about the system it is possible to put it in order and describe system of problem when the problem occurs. For this purpose the System Operator (SO) will be applied [3]. SO outlines different levels of systems making it easier to understand what elements are playing a role during time when that problem appears.

With this set of information it is possible to describe the problem addressing different parts of system that can be associated with problem appearance. Using TRIZ idea of problem expression, problems will be described in the form of contradictions [4]. Different points of view on a problem and usually several parts of a system that are involved in the action with an identified problem, cause that several problem expressions are formed. Each of these expressions carries valuable information about a problem and a group of contradictions carries even more information. As they have a shared origin in the system already described by us, they have also mutual relations. Network of contradictions proposed by OTSM-TRIZ is depicting these relations linking several contradictions, formed as expressions of a described problem, into a network [5].

All of these stages will be presented in the part following the technical description of physical system of production line, where a case study problem appears.

All elements mentioned/listed in the problem description benefit to a set of elements and actions, which may be used in the problem solving process. In fact a quality of a problem description process can be measured by ratio of number of elements that are used in the problem solving process to these that are left out. The problem description should consist of key elements for the following problem solving process. Less unused elements mean less time consumption and less distraction from the right path.

3 Physical System

The first step of physical system description is problem formulation. In this stage the defect of glazing tiles has been physically described. First of all the tiles profile have been measured with the use of optical profilometer (Fig. 2).

The changeability of the tested tile profile is unacceptable because the profile amplitude is larger than specification limit. The limit has been determined according to human ability to see the surface defects. The amplitude of the tile profile larger than 9 μm indicates the tile defect.

In the second step of the physical system description, the frequency of streak has been calculated Eq. (1–3) and (Fig. 3).

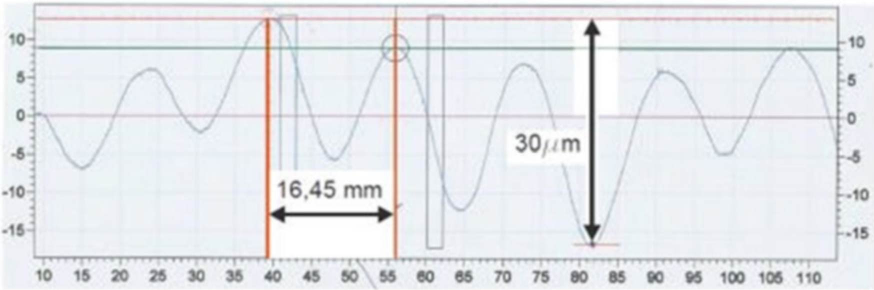

Fig. 2 Characteristics of tiles profile after glazing process

$$\frac{T_i\,(330mm)}{l_c(16.45mm)} = N_s\,(20) \tag{1}$$

where: T_t – *tile length*;
l_c – *distance between streaks in cycle time*;
N_s – *number of streaks on the tile.*

$$\frac{T_g\,(420ms)}{N_s(20)} = C_t\,(21ms) \tag{2}$$

where: T_g – *glazing time of one tile*;
N_s – *number of streaks on the tile*;
C_t – *streak cycle time.*

$$\frac{1}{C_t\,(21ms)} = f\,(47{,}61Hz) \rightarrow f \cong 50Hz \tag{3}$$

where: C_t – *streak cycle time*;
f – *frequncy of streaks.*

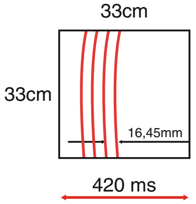

Fig. 3 Frequency of streak after tile glazing process

All the calculations come from measurements using high speed camera and vibrometer. The measurements have been conducted on a production line in tile manufacturing company in Eastern Europe (Fig. 4).

Consequently, the tile glazing process has been mathematically described. This description is based on glazing diagram (Fig. 5) presenting all movable and

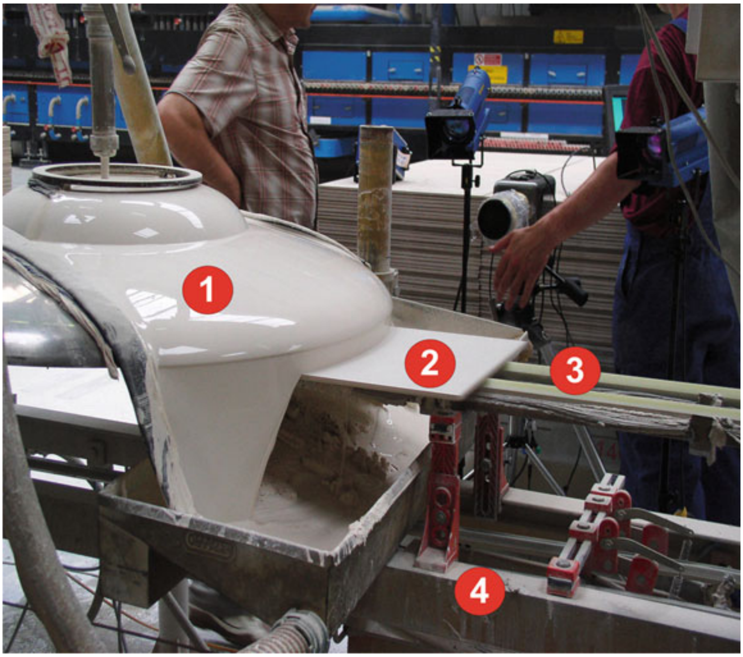

Fig. 4 Tile glazing process (1-Glazing hat and glaze, 2-Tile, 3-Belt conveyor, 4-Frame of conveyor)

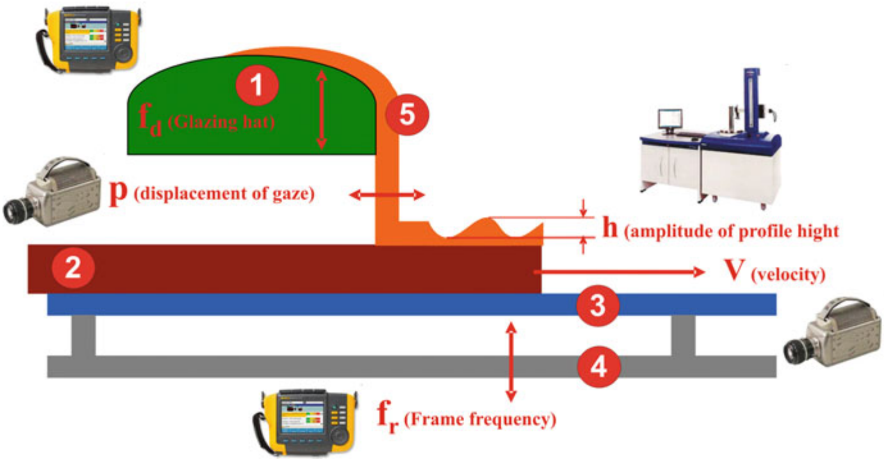

Fig. 5 Diagram of tile glazing process and defect result of glazing process (1-Glazing hat and glaze, 2-Tile, 3-Belt of conveyor, 4-Frame of conveyor. 5-Glaze)

immovable elements in the glazing phase. In the glazing process description the elements displacements have been recorded in order to describe the phenomena of glazing defect in tile manufacturing (Figs. 6 and 7).

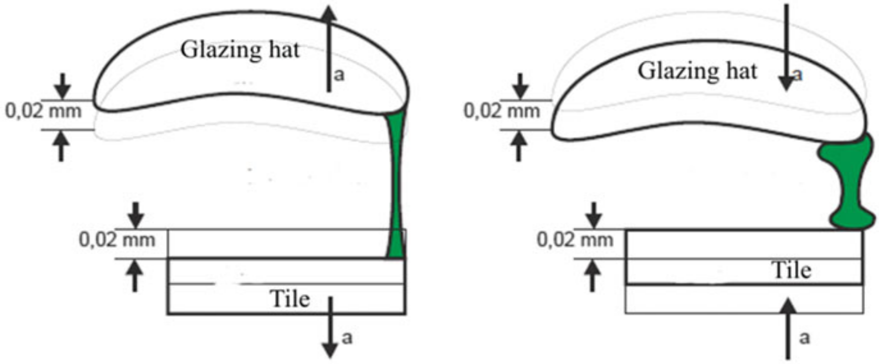

Fig. 6 Phenomena of glazing defect in tile manufacturing process

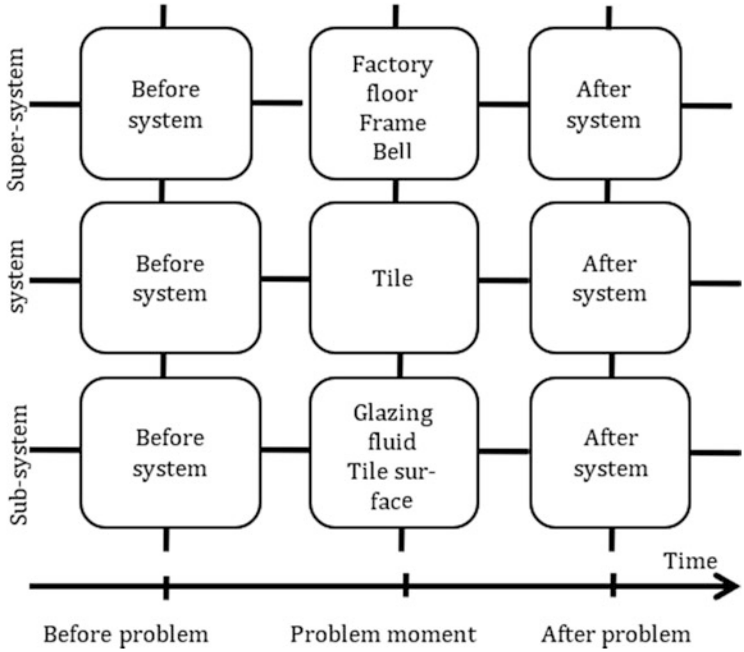

Fig. 7 System operator—elements noted during interview with expert

4 Two Methods

Following presentation of two methods starts with an ad hoc method. This method was constructed out of TRIZ tools as a support during discussion with expert on a subject of technical problem already presented. Ad hoc method makes a use of TRIZ tools sometimes necessarily reduced to a form more handy during a life interview with expert. The objective of an ad hoc method was to gather enough information for problem solving process, therefore ad hoc method qualifies as a problem description approach.

Extended method, built later on after interview with expert, repeats utilization of the same tools as in ad hoc method but in a complete form and adds other tools for overall quality. Description of particular tools in following paragraphs is presented one time i.e. when a tool is being introduced in ad hoc method, then if a tool is used also in extended method the proper reference to preceding point including introduction is made.

5 Description of System: Ad Hoc Method

Ad hoc method applied during an interview with expert used three tools i.e.: elements of System Operator, contradiction model, definition of time borders.

System Operator (SO), sometimes called also Multi Screen Scheme of Thinking, is a tool that organizes a way of thinking of person describing a system. SO is constructed along two axis, horizontal time axis and vertical level of organization. Vertical axis spans from sub-system, through the system, up to the super-system. The reference level is a system, which is being described. A system makes a part of some super-systems and at the same time is composed out of sub-systems. This vertical organization is presented for a particular moment in time, usually before time of problem occurrence and after. Each system named in a box, or a display (depends on used vocabulary), can be extended into next SO.

In ad hoc method SO was used in simplified form developing only the super-system, and subsystem structure at the moment of problem. (0) Other moments in SO were neglected at a time of interview. However, indication about remaining time moments necessary to complete SO, were kept in mind and used as a guideline when collecting data about time borders of problem occurrence. SO form noted during interview with expert presents arrangement that was later modified and completed.

5.1 Contradiction

Contradiction is a model of problem expression, it is also a primary way to express a problem according to TRIZ. Contradiction is constructed on two opposite values of a parameter of an elements. Desired solution to a problem described in form of contradiction should satisfy two opposing values. In order to use contradictions quickly their model was noted in shorter form and remaining elements were kept in

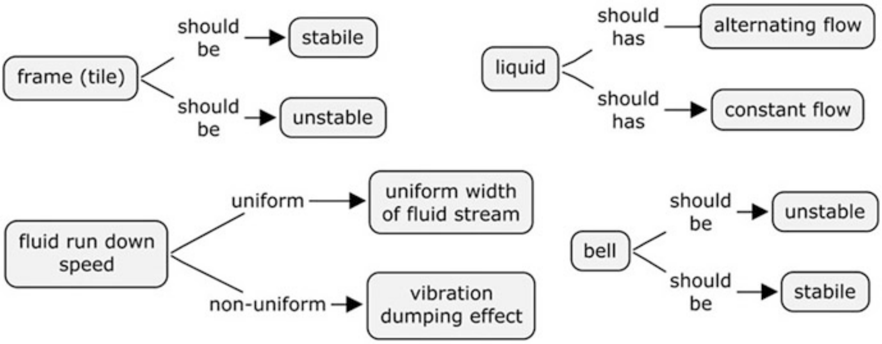

Fig. 8 Contradictions noted during interview with expert

mind (Fig. 8). For the comparison with complete model of contradiction see Figs. 11, 12 and 13.

Time borders definition concentrated on description of a particular moments of time where the identified problem appears plus moments just before and after. Time was described in milliseconds thanks to recorded onsite measurements.

6 Description of System: Extended Method

Extended method benefited from data and information gathered from the interview with expert when ad hoc method was used. Contrary to ad hoc method in extended problem study there was a time to introduce more tools that help to describe a problem better. Description of system border and Substance Field Resources (SFR) tools were introduced at the beginning. System Operator and contradictions were completed. Towards the end a network of contradictions was built and critical-to-X features were disclosed. Following paragraphs describe one by one, particular elements of extended method of problem description.

6.1 System's Border

Description of a system's border makes a distinction between a system and its environment. From this point of view, system consists of elements and relations that are influenced directly by a problem. Environment surrounds a system and by imposing limitations defines the system border from exterior. Conditions and restrictions composing a system's environment, from the point of view of system, can be considered as impossible or difficult to change. However, constructing

Table 1 System border described in three categories

System border		
Dimension	Main set	Objects
Space	Tile glazing unit	Bell, fluid, tile, frame with transportation belt, ground floor
Time	Contact time of tile and glazing liquid	Liquid flow off time on a bell, liquid flow off time from a bell on a tile
Organization	Tiles glazing process	

description of system's border, information about environment should be considered also as resource of potential solutions in the problem solving process. Description of a border for the tile glazing process is described in Table 1.

6.1.1 Border From the Outside

In terms of space, outside border can be described as elements of tile production line that precede and follow after tile glazing unit. Time outside border of a system, is time before glazing and after glazing.

6.2 SFR [2]

In order to see beyond visible mechanical elements and products used in the tiles production process, it is advisable to use a concept called SFR (Substance, Field, Resources). This concept facilitates construction of a list of substances, fields of influence e.g. gravitation, magnetic, electro-magnetic and resources in other forms (Table 2). Information disclosed with SFR should refer to a system that is being described. SFR concept may be also used in the description of system border.

Table 2 SFR

General approach		
Substance	Field	Resources
Tile ceramics, glazing liquid,	Gravitation, light	Metal, plastics, tile support, conveyor belt
Approach considering sub- and super-systems		
Substance	Field	Resources
Air	Electromagnetic, mechanical field	Recycled glazing fluid, overflowing glazing fluid

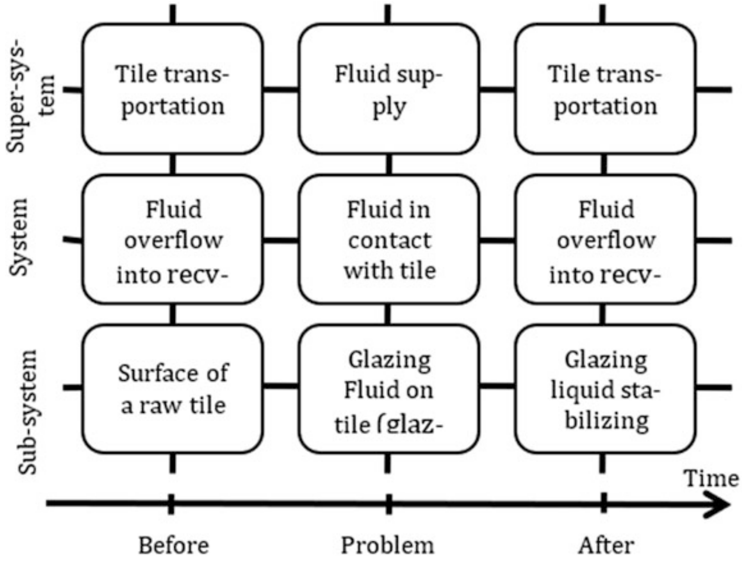

Fig. 9 System operator—Glazing fluid

SFR concept is particularly effective when used together with the System Operator introduced in following paragraph.

6.3 System Operator [3]

For the purpose of case study it was decided to build four separate SO for a bell, glazing fluid, tile and conveyor belt frame. In this paper we would like to present two of them as examples, one describing glazing fluid (Fig .9), second describing a bell (Fig. 10).

Application of SO provides a structure that guides other activities within problem description. For instance, utilization of the SFR concept following constructed SO structure, organizes a list of SFR elements. Thanks to this effect the list of SFR may be shorter and definitely more operable.

6.4 Contradictions

Introduction to contradictions have been made in section with ad hoc method. The technical system for glazing tiles includes: glazing fluid, bell for glazing fluid distribution, tile and transportation system on a frame.

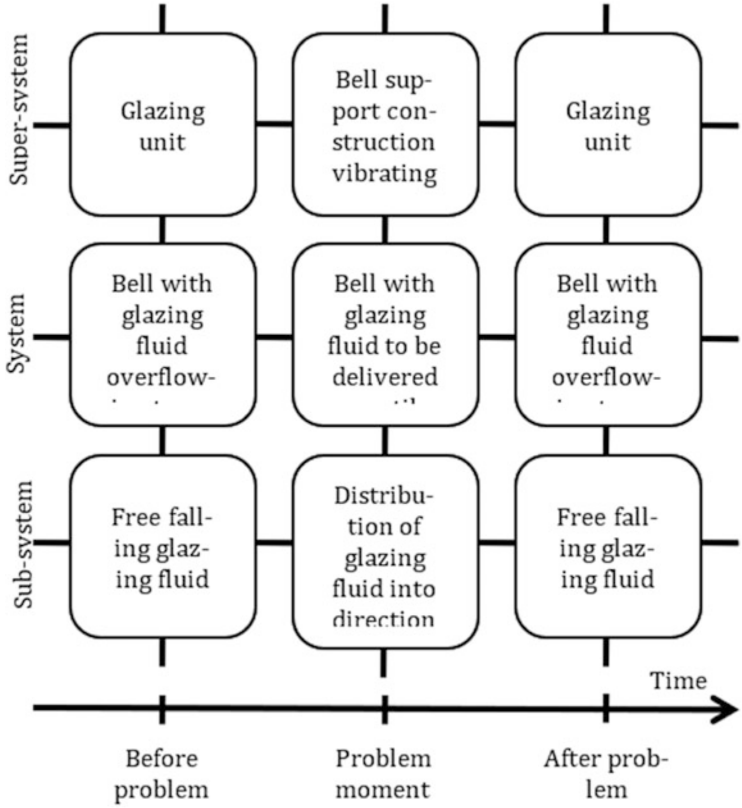

Fig. 10 System operator—Bell

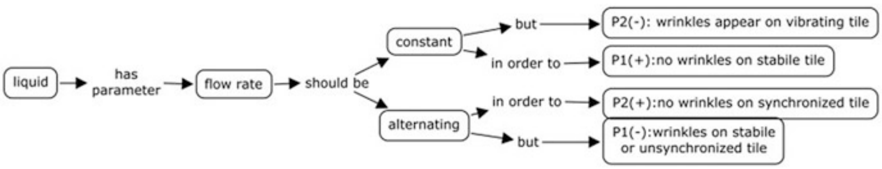

Fig. 11 Technical contradiction TC 1

6.4.1 Contradiction 1 (Fig. 11)

Technical contradiction (TC) 1.1.: if there is a constant flow of a glazing fluid, then it is evenly distributed on a stabile tile, but if tile is vibrating glazing covering is wrinkled.

TC 1.2.: if there is an alternating flow of glazing fluid, there are no wrinkles on a tile vibrating in synchronized way, but if tile is stabile or unsynchronized wrinkles appear.

6.4.2 Contradiction 2 (Fig. 12)

TC 2.1.: if tile transportation (frame) is stabile there are no wrinkles on a tile covered by stabile glazing fluid stream, but if glazing fluid is vibrating, wrinkles will appear.

TC 2.2.: if tile transportation (frame) is not stabile, there are no wrinkles if glazing fluid stream is alternating and synchronized, but if glazing fluid stream is stabile or unsynchronized, wrinkles will appear.

6.4.3 Contradiction 3 (Fig. 13)

TC 3.1.: if tile is flat, then constant flow of glazing fluid will cover it evenly, but if glazing fluid flow is alternating then wrinkles will appear.

TC 3.2.: if tile is wrinkled, then synchronized alternating flow of glazing fluid is compensated by wrinkled tile, but unsynchronized or constant flow cause wrinkles to appear.

6.4.4 Network of Contradictions (Fig. 14)

OTSM-TRIZ further development of TRIZ theory introduces a network of contradictions [5, 6]. For the purpose of problem description, a network of contradictions provides a feature to gather and see all contradictions in one place. Contradictions are

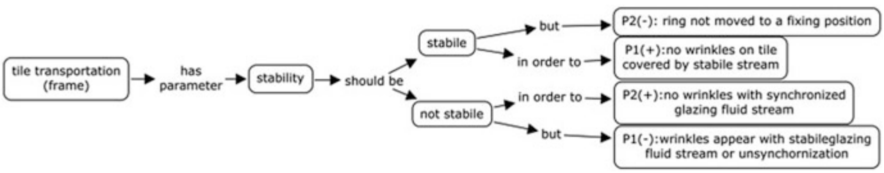

Fig. 12 Technical contradiction TC 2

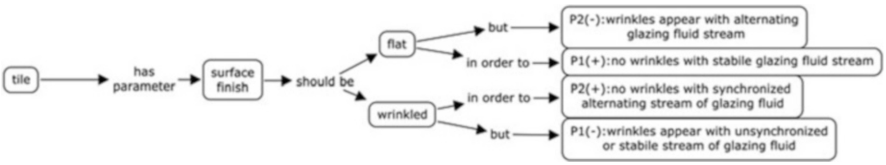

Fig. 13 Technical contradiction TC 3

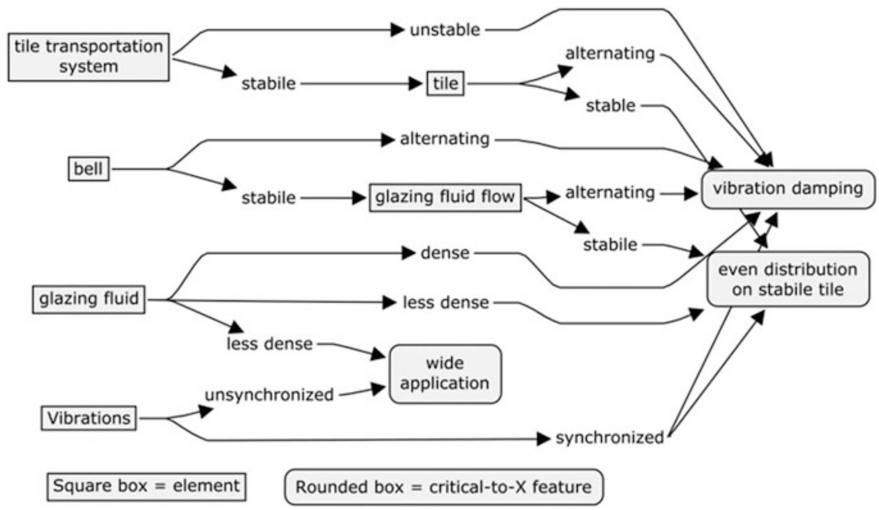

Fig. 14 Network of contradictions

Table 3 Comparison of ad hoc and extended method for problem description

Name of a tool	Ad hoc method	Extended method
Border of a system	Time border	+
System operator	+	+
System field resources (SFR)		+
Contradiction	+	+
Network of contradiction		+
Critical-to-X feature		+

interconnected and present an overview of mutual influences. Network is constructed with two types of boxes and described links. Square box contains a name of element, box with rounded corners is a critical-to-X feature. Critical-to-X feature translates to feature critical to issue named X. X is different depending on the problem that is under study. In case study presented in this paper X is a quality of tile glazing.

Linking lines are also named using the contradiction logic to have always two opposing values linking element and different critical-to-X features.

6.4.5 Critical-to-X Features

Extended problem description by the means of network of contradictions leads to a great number of elements and critical-to-X features. Large network has to be converted into smaller one in order to keep it's operability respecting human's limited perception abilities. Process of convergence leads to integration of critical-to-X features that all together are key points to concentrate on in problem solving process or other kind of further study on the problem (Table 3).

7 Conclusions

Two ways to perform a problem description presented in this paper have their strengths and points for improvement. Extended study following an ad hoc method revealed elements, which up to our estimation can be successfully included in ad hoc method. Application of tools presented in the extended method of problem description, delivers a complete and systemized view of data and information. Presented assembly of tools can successfully support knowledge acquisition in interviews with experts.

Most of tools recommended for utilization in problem description require performing some sketches but it can be easily conducted in notepad or whiteboard. All tools used in this paper belong to TRIZ and OTSM-TRIZ.

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TRIZ-Based Approach for Process Intensification and Problem Solving in Process Engineering: Concepts and Research Agenda

Didier Casner, Pavel Livotov, Mas'udah, and Patricia Kely da Silva

1 Introduction

Process engineering (PE) deals with the design, operation, control and optimization of chemical, physical, and biological processes. It has applications in a wide range of industries, such as chemical, petrochemical, and pharmaceutical industries. In order to remain competitive in future these industries have to establish a systematic approach for process intensification and to enable continuous and disruptive innovation. The process intensification (PI) is understood as a part of the knowledge-based engineering (KBE) and can be defined as any significant technological development leading to more efficient and safer processes. The PI databases of new technologies and equipment allow to faster achieve the goals of innovation.

Among different innovation approaches, the modern Theory of Inventive Problem Solving (TRIZ) is today considered as the most comprehensive, systematically organized invention and creative thinking methodology for the knowledge-based innovation (KBI) [1, 2]. One of the main advantages of TRIZ is that it allows to find new inventive solutions for a given problem in a systematic way by using the entire potential of science and engineering, also outside of the field of originally formulated problem [3].

Since process engineering industries have only recently started to apply TRIZ for the development of new processes, only a few studies can be cited in this context. Among the recent research works related with the development of new chemical, physical, and biological processes, there has been one proposal to combine TRIZ and Case-Based Reasoning (CBR) in chemical engineering [4]: in this joint approach the CBR would be applied to solve new problems using the experience

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obtained from previous successful solutions in the same technical domain, and it would be further enhanced by TRIZ to access other engineering fields. However, more recent investigations have shown that direct merging of CBR and TRIZ do not result in positive synergy effects and have even outlined the risk of one approach weakening the other [5].

A few studies on the application of TRIZ in process engineering have focused on the problem-solving step, such as the development of adapted contradiction matrix [6], or on the application of TRIZ inventive principles and standard solutions in chemical engineering [7–11]. The authors of [6] have introduced 14 technical parameters for the formulation of contradictions and propose additional eight inventive principles to be applied in chemical engineering and mixing operation in particular.

The study [7] outlines the necessity to adapt TRIZ for the domain of process engineering and illustrates the proposed TRIZ modifications with a case study dealing with safety issues of chemical processes.

The application of TRIZ for safety issues in chemical reactors has been discussed in a case study [8], in which 39 engineering parameters for formulating contradictions are condensed to six categories such as process disturbance, design, mechanics, human operator, natural hazard, and materials.

The authors of [9] have reported successful application of different TRIZ methods and tools, such as inventive algorithm ARIZ, Function Oriented Search, and Cause–Effect Chain Analysis (CECA) in the development of chemical or bio-chemical products and technologies.

Another work illustrates the application of TRIZ-based tools in problem solving and forecasting in the field of applied chemical engineering in the automotive industry [10].

The study [12] analyses the relationship between creative and standard approaches in the design of process control and suggests a new systematic approach to heuristic control design systems, which is illustrated with several examples related to the cement manufacturing process.

In order to reduce the negative environmental impact of the chemical industry, a TRIZ-based computer aided eco-innovation system has been proposed to support the engineers in the preliminary design [11]. The approach involves a number of steps, starting with the initial problem analysis and problem formulation through to generation of possible and feasible ideas. It reduces the level of TRIZ abstraction and applies TRIZ tools, such as physical, chemical, biological, and geometrical effects, on the level of concrete solutions, which is typical for the Case-Based Reasoning [4].

A forecast of PE-equipment evolution with TRIZ, including inventive solutions and resolved contradictions, has been demonstrated with the example of black oil coking unit evolution from horizontal vessels to delayed coker units and then to continuous carbonizers [13].

A scheme for reorganizing TRIZ databases for the search of solution principles for unit operations in food processing has been proposed in [14]. Two practitioner's studies present chemical examples [15] and interpretations [16] for 40 TRIZ inventive principles, relevant for process engineering.

The study [17] illustrates the function analysis aimed at building the network of TRIZ evolutionary trends using the example of tablet production in the pharmaceutical industry. The papers cited above and some earlier publications [18–20] report good TRIZ applicability in the resolution of localized design problems in PE equipment but hardly mention the issues of process analysis and process intensification comprehensively.

Since any manufactory process in PE typically consists of numerous steps involving appropriate equipment, an isolated case of successful TRIZ application does not automatically guarantee satisfactory results on the process level. Therefore, a holistic TRIZ-based innovation approach for process intensification with pre-defined steps and feedback loops is required. This approach should include the following steps:

1. Identification and ranking of solution-neutral needs and requirements of the industry, society, and customers/users for process intensification.
2. Formulation of the innovation tasks and problems, including identification of engineering contradictions or contradictory requirements.
3. Systematic generation of ideas and inventive problem solving with TRIZ tools enhanced for application in PE.
4. Creation of innovative PI concepts on the basis of solution ideas.

The research work presented in this paper belongs to the initial part of the a 3-year-long European project "Intensified by Design® platform for the intensification of processes involving solids handling", funded by the European Commission under Horizon 2020 SPIRE (Sustainable Process Industry through Resource and Energy Efficiency) program.

The platform will be developed in co-operation with 22 research and industrial partners from eight countries. It will allow to facilitate process intensification (PI), design and optimization in the field of solids processing by using currently existing and completely new approaches, based on the use of robust process data and on statistical, analytical, risk management, and innovation methodologies.

2 Process Intensification (PI)

Process Intensification (PI) dates back to the research of Prof. Ramshaw and his co-workers [21] in the late 1970s and is "commonly seen as one of the most promising development paths for the chemical process industry and one of the most important progress areas for modern chemical engineering" [22]. It can be also defined as "the strategy for dramatic reducing the size of chemical plant needed to achieve a given production objective" [21] and as "any chemical engineering development that leads to a substantially smaller, cleaner, safer and more energy

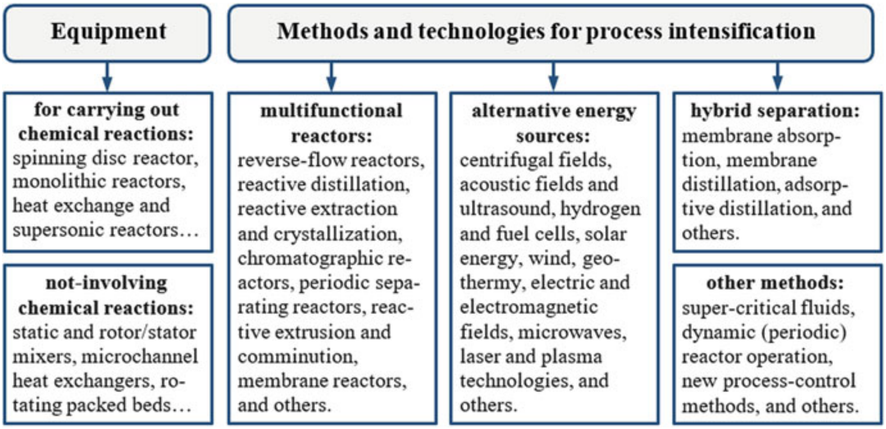

Fig. 1 Process intensification equipment and methods [23, 25]

efficient technology" [23]. As stated in [21], PI satisfies at least one of the seven key objectives of industrial growth, defined in [24]:

- capital investment reduction
- energy use reduction
- raw material cost reduction
- increased process flexibility and inventory reduction
- ever-greater emphasis on process safety
- increased attention to quality
- better environmental performance.

PI covers a wide range of processing equipment and methodologies [21, 23, 25]. As shown in Fig. 1, process intensification can be divided into the following two categories:

- equipment (reactors, mixing, heat or mass-transfer devices, etc.)
- methods (extraction, separation, absorption, techniques using alternative energy sources and new process-control methods, etc.)

The application of these processing methods can lead to contradictory effects, i.e. the intensification of one property may cause the worsening of another parameter as outlined in [26, 27].

It is also important to note here that some technological PI principles presented in [25] are highly consistent with the evolution laws of technical systems in the TRIZ methodology, developed by G. S. Altshuller (first publication in 1956) and his co-workers [3]. Such PI principles include the following [25]:

- miniaturization of process equipment
- transition from the macro- to meso- and micro-level

- enhancement of the force fields (mechanic—acoustic—electric—electromagnetic—light energy)
- enhanced surface configurations

The existing PI databases with intensified equipment types, methods, and applications enable engineers to identify and implement appropriate process-intensifying solutions faster in accordance with the objectives and constraints of their development tasks. Even if the PI approach might not always be as effective as expected, it should be taken into consideration at the beginning of any process development or optimization [27].

3 Empirical Research

In order to evaluate the possibilities of TRIZ application in process engineering, especially as a supporting innovation toolbox for process intensification, an analysis of international patent literature in the field of solid handling in ceramic industry was performed. This analysis has the following objectives:

1. Identification of the problems and invention tasks as solution-neutral requirements.
2. Identification of the engineering contradiction in terms of TRIZ.
3. Formulation of requirements for the further development of the existing inventive TRIZ tools for their application in PE.

The research scope was limited by selecting 100 patent documents from 15 countries with the application date between 2008 and 2015. The general procedure of the patent analysis is illustrated with an example in Table 1.

The analysis demonstrates that all inventions promise to solve several problems in PE but also generate negative side effects or the so-called secondary problems. In this context, the emphasis in the proposed new method is put on the anticipation of the secondary problems in the patent documents, which in the next step results in the extraction and prediction of possible engineering contradictions within technical systems.

3.1 Method for Extraction and Prediction of Contradictions

The analysis of 100 full-text patent documents (patents or applications) identified more than 400 problem issues in total, which should be improved by the inventions.

Each patent text deals on average with four problems that have to be solved. However most of these problems are identical, and the elimination of similar issues leads to 125 unique problems, such as low yield, high energy and water consumption, variation of the granule size etc., which can be combined in 35 groups. This list

Table 1 General procedure of the performed patent analysis

Step	Description	Example US020130248625A1 [28]
1	Goals of inventions: initial problems in the equipment and processes involving solids handling in the ceramic industry.	Reduce water consumption and pollution through atomization; reduce air pollution due to entrained fine mineral particles; decrease the temperature of operation; . . .
2	Translation of the initial problems into a list of solution-neutral requirements or parameters.	Reduce environment pollution; Reduce water consumption; Reduce energy consumption; . . .
3	Description of the main solution principles as listed in the patent claims and description.	Granulation by agglomeration is performed through dry-phase grinding, which eliminates the wet phase and the need for spray drying. . .
4	Advantages of the proposed design solution, equipment, process or technology.	Reduced water consumption; low energy consumption; reduced size of equipment; zero use of additives; reduced costs; . . .
5	Disadvantages or anticipated secondary problems of the proposed invention, which may hinder its implementation.	Pre-treatment of raw materials; limited range of particle size; Lower quality parameter (. . .); Higher cleaning efforts; Control of water release; . . .
6	Identification of engineering contradictions between the advantages and the secondary problems of inventions	Lower environmental impact vs. quality parameters; Reduced water consumption vs. complicated process control; . . .
7	Keywords for semantic classification	Granulation, agglomeration, ceramic, spray dryer, dry phase, wet phase, atomization. . .

Table 2 The impact of inventions on the identified PI requirements: positive effect: +1; negative: −1; neutral: 0 (example)

Solution-neutral requirements for process intensification	Patent 1	Patent 2	Patent 3	. . .	Patent 100
1. Reduce energy consumption	0	+1	0	. . .	0
2. Reduce water consumption	+1	+1	−1	. . .	+1
3. Reduce environmental impact	0	0	−1	. . .	−1
. . .	. . .	. . .	. . .	. . .	. . .
125. Increase product yield	0	0	0	. . .	+1

of unique problems can be used for easier capturing of the expected negative effects (secondary problems) of the inventions.

In accordance to the method for quantitative ranking of innovation tasks for products and processes [29], the identified problems are expressed as solution-neutral requirements for process intensification. They serve as a checklist for verifying solutions described in patents documents as shown in the example in Table 2. The numbers in the table indicate the impact of patented solutions on the process intensification requirements, i.e., the invention solves the problem (positive effect:

Table 3 The matrix of contradiction occurrence frequencies for prediction of contradiction probability between the PI requirements (fragment)

PI solution-neutral requirements	1. Reduce energy consumption	2. Reduce water consumption	3. Reduce environmental impact	...
1. Reduce energy consumption		C_{12}	C_{13}	...
2. Reduce water consumption	C_{21}		C_{23}	...
3. Reduce environmental impact	C_{31}	C_{32}		...
...	...	...	...	

+1), the invention causes a secondary problem (negative effect: −1), or there is no effect (=0).

The obtained information about existing correlation between the initial problems to be solved by the inventions and the corresponding secondary problems can help to identify or to predict contradictions in the field of analysis. Table 3 shows values C_{ij}, which correspond to the frequency of secondary problem occurrences between the solution-neutral requirements for the process intensification. Contrary to the deterministic definition of contradictions used in the classical TRIZ, the identified contradictions are expected here with a certain degree of probability. In general, the C_{ij} values can be interpreted as correlation coefficients between different requirements, reflecting positive or negative interdependencies.

The identified solution-neutral demands can be combined into a lower number of problem clusters as shown in the diagram in Fig. 2. The relative frequency of occurrence of each problem cluster in the analyzed patent documents is represented by the dark bars, while the frequency of anticipated disadvantages (secondary problems) of inventions is shown by the blue bars. The analysis shows that the inventive goals encountered in the patent literature are related with quality issues (48%), high costs (37%), and environmental concerns (18%). On the other hand, the most frequent secondary side effects are high costs (66%), environmental impact (48%) and complexity of equipment or processes (32%).

3.2 Process Mapping Technique

For the identification of problems and contradictory requirements, the System Operator, also known in TRIZ as the multi-screen analysis [2, 3], can be used together with function analysis as illustrated in example of granulation process in Table 4.

Similarly, to the well-known classical application of the System Operator (super-system—system—subsystems) in the design process, its adaptation for processes involves the following levels:

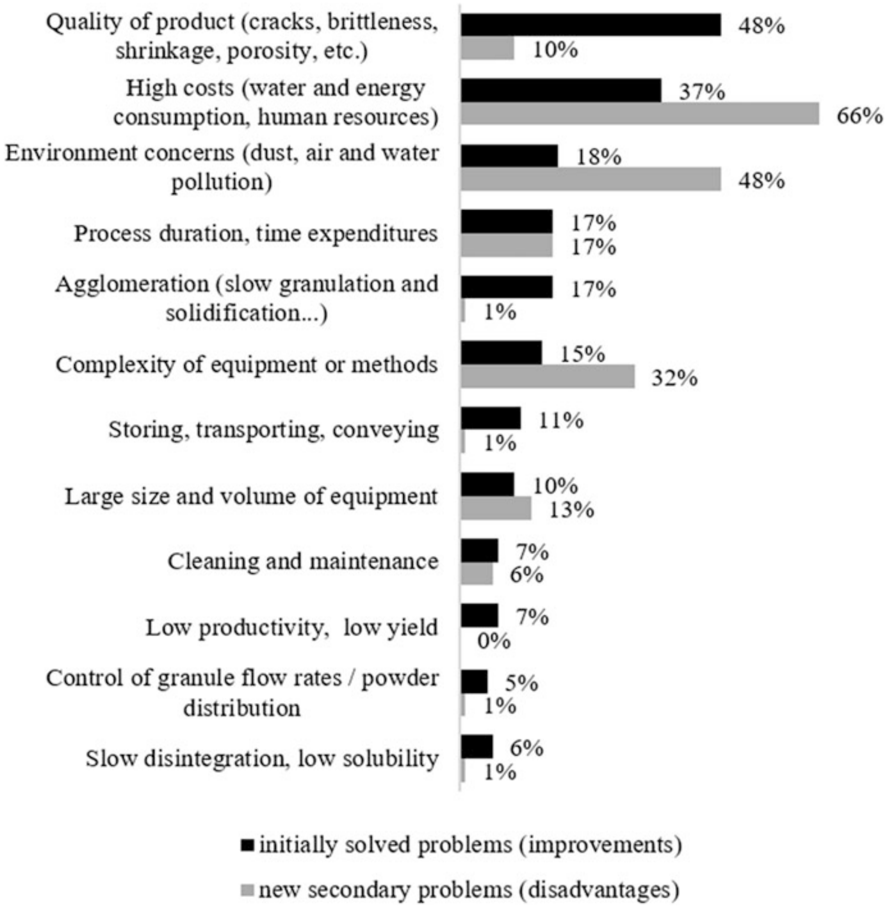

Fig. 2 Initial problems solved by the inventions and new secondary problems (disadvantages), iden-tified from 100 patents (multiple choice)

Table 4 Process analysis with System Operator (fragment)

Super-process	manufacturing of ceramic parts		
Process	**wet granulation**	**dry granulation**	**…?**
Sub-process (process steps)	…	…	…?
	wet milling		…?
	homogenization		…?
	pumping/transport		…?
	atomization		…?
	drying	…	…
	…	…	… ?
	I. Earlier existing process	*II. Available PI solution*	*III. Future PI solution*

Tasks / positive functions
+ target granulate moisture …
Negative effects:
- high energy consumption …

- the upper-level *super-process*: manufacture of ceramic parts, which includes granulation;
- the *process* level: the granulation process;
- the *sub-process* level: essential steps of the granulation process.

Column *I* presents the earlier existing or current generation of the process and the column *II*—the already available or known PI solution with its benefits and disadvantages. Finally, the column *III* should help to shape or forecast the new enhanced PI solution to be realized in future.

The *sub-process* cells in Table 4 contain information about the major tasks or jobs of the process steps and the accompanying undesired properties or harmful effects. In addition, all sensitive or key quality parameters, the input and output data, the physical and energetic state of involved materials or substances and other resources and relevant information are documented.

The process mapping can be accomplished by the Root-Conflict Analysis RCA + − a new TRIZ method [30], which transforms the obtained information into graphs, thereby visualizing and structuring cause-effect chains and engineering contradictions.

4 The Concept of the TRIZ-based Approach for PI

As demonstrated in Sect. 3 any process-intensifying solution can cause one or more negative side effects or secondary problems. Moreover, one PI objective, e.g., reduction of energy consumption can conflict with other objectives, for example equipment costs or environmental impact. Thus, numerous barriers in the form of contradictions hinder the implementation of the existing PI solutions.

Even if the resolving of contradictions belongs to the major application domain of TRIZ methodology, the application of TRIZ in process engineering faces the following challenges:

1. Complete identification and ranking of solution-neutral demands in complex technical systems, such as manufacturing processes in PE.
2. Formulation of the problems in PE in terms of engineering and physical contradictions, including complete identification of contradictions and contradiction chains.
3. Design and multi-objective optimization of the PI solution concepts, including solutions for several partial problems.
4. Translation of the existing TRIZ tools and development of new inventive principles for an easy and error-free application in PE by non-TRIZ specialists.
5. Expansion of the existing PE/PI knowledge base in order to find new disruptive PI solutions using knowledge from other fields of science or engineering.

The graph in Fig. 3 illustrates a general algorithm for problem solving in PI after a problem or a set of problems is already identified.

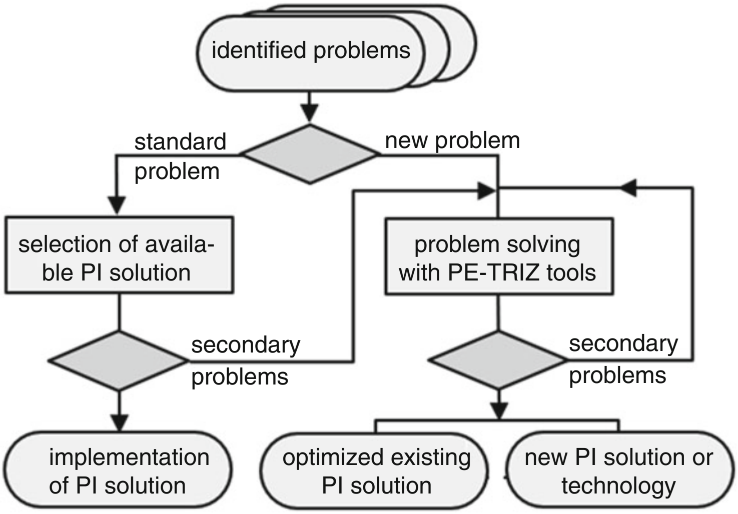

Fig. 3 Basic algorithm of TRIZ support in problem solving in Process Engineering PE

In accordance with the algorithm, it should be first checked whether the problems can be considered as already known standard problems. If yes, an appropriate PI solution can be selected for further implementation. If the application of this PI solution faces secondary problems, the corresponding TRIZ tools for PE can be used to limit negative effects.

If the initial problem is completely or partially new, its inventive solution is supported by the TRIZ application, which can lead to two complementary PI concepts:

1. optimization of the existing PI solution (resources-oriented and thus cost-saving)
2. development of a completely new PI solution or technology.

Thus, the TRIZ-based approach for process intensification should include a computerized innovation toolbox to supporting designers and industry in the following main tasks:

- analysis of the initial problem situation in PI
- identification of solution-neutral requirements and contradictions
- development of specifications and innovation strategy for PI
- anticipation of secondary problems in new PI solutions
- fast and inventive problem solving
- solving of the measurement and control problems
- cost reduction for existing and new PI solutions
- enhancement of creativity.

The final decision about the functionality of innovation toolbox components will be based on the thorough analysis of typical problems, competences, and needs of industrial companies and R&D organizations involved in the process intensification issues in PE.

5 Conclusion and Outlook

Since the implementation of PI solutions leads to a technologically new equipment in the production plants and often causes secondary problems and/or significant investments, TRIZ methodology can limit these negative side effects of PI.

On the one hand, the application of the TRIZ-based approach for PI helps to identify secondary problems and to predict contradictions in advance and enables a smooth loss-free shift to a new technology without "teething" problems.

On the other hand, TRIZ helps to mobilize resources of the existing processes and to reach the maximum efficiency with a minimum of expenditures, increasing the maturity level of existing technologies in terms of low investment and resources-oriented innovation.

As a complex innovation technology, TRIZ can be also used to develop completely new breakthrough solutions for PI, to forecast evolution of processes and equipment, and to inventively solve the bottle-neck problems. The future work will focus on the development of the TRIZ-based toolbox adapted for PI, including its computerized realization in the context of Computer-Aided Innovation (CAI).

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Problem Definition and Identification of Contradictions in the Interdisciplinary Areas of Mechatronic Engineering

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1 Introduction

Over the past few decades, industrial companies have entered a new industrial age characterized by the demand on continuous innovation [1]. In the current highly competitive industrial context, companies should, on the one hand, develop products that are of higher quality, more efficient and complex but are also less expensive in order to satisfy the increasingly demanding B2B and B2C customers; on the other hand, companies should renew their product range more frequently.

Mechatronic products exemplify this tendency towards complexity. Developed since 1969 [2, 3], they can be defined as multidisciplinary technical systems resulting from the integration of technologies from mechanical, electrical, control and computer engineering. The design process in mechatronics requires higher competences and problem-solving abilities of engineers to deal with the complexity and interdisciplinary challenges.

The innovative design methodologies and computer-aided tools, developed in recent decades, are expected to support engineers to develop new products faster. Among all innovation methodologies, the theory of inventive problem solving TRIZ [4, 5] is today considered as the most organized and comprehensive methodology for invention knowledge and creative thinking [6]. In the recent decades, new analytical methods for comprehensive problem analysis and contradictions identification have been continuously developed in addition to the classical TRIZ problem-solving tools [7–16].

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Moreover, in the first static law of system evolution, the law of the completeness of the parts of the system, formulated by Altshuller [5] states that “Any working system must have four parts: the engine, the transmission, the working unit and the control element”. In the present circumstances, it implies that systems tend to become more interdisciplinary and mechatronic. Other TRIZ evolution laws and patterns, such as increasing adaptability of systems, increasing controllability of fields, and the increasing degree of automation, also confirm this statement.

Among the different steps involved in the TRIZ-based problem-solving process, the definition of the problem and the extraction of contradictions are two of the most comprehensive, time-consuming, and critical steps of the process. The solution obtained using TRIZ strongly depends on the level of completeness of the problem analysis and the abilities of the designers to identify the core contradiction(s) in the problem situation. The complexity of these tasks increases when dealing with mechatronic problems. Indeed, in an identified mechatronic problem the contradictions can result from three different aspects:

The monodisciplinary contradictions that correspond to the contradictions appearing within a sub-system (a module of the system related separately to the mechanical or electrical subsystem, for example).

The interdisciplinary contradictions resulting from the interaction of mechatronic subsystems (mechanics, electrics, control and software) or from the integration of different technologies in a mechatronic subsystem.

The contradictions resulting from an uneven development of separate parts of the system [5, 7].

Our observations are based on more than 20 years of systematic problem solving in mechatronics, and they show that engineers primarily focus on the monodisciplinary problems and can oversee multidisciplinary interactions that may arise from the lack of time or experience in systematic problem definition. Consequently, complex contexts can often be simplified as well as the opportunities and system resources are not utilized in the proposed solutions.

A TRIZ-based approach, presented in this paper, should help both engineers and students to identify interdisciplinary contradictions in mechatronic problems faster and without in-depth TRIZ knowledge. The approach helps the designers to do the following: 1) to define the mechatronic problem faster; 2) to completely extract the mono- and interdisciplinary contradictions from the problem; 3) to rank identified contradictions as separate sub-problems in accordance with their relevance for the defined objectives of the initial problem situation.

2 Problem Definition Approaches

This section presents a short overview of the main TRIZ-based methods and tools related with the problem definition and the identification of technical or engineering contradictions summarized in Table 1. The known TRIZ tools supporting the problem definition include Innovation Checklists [4], Substance-Field Analysis

Table 1 The main TRIZ tools for problem definition and contradiction extraction

Step	TRIZ tools	Other tools
1. Problem definition	– Innovation checklists and situational analysis – Function analysis – Component analysis – Function modeling – System operator – Substance-field analysis – Cause-effect chain analysis (CECA) – OTSM network of problems – Problem graph (IDM-TRIZ) – . . .	– Root-cause analysis (RCA), – Fishbone diagram – Others (APTE, SysML, . . .) – . . .
2. Identification of contradictions	– Function analysis – Inventive algorithm ARIZ – Cause-effect chain analysis (CECA) and diagrams – Root-conflict analysis (RCA+) – Network of contradictions analysis – . . .	

and the System Operator (Multi-Screen Analysis) [5, 15], Component and Function Analysis [9, 17], Function Modeling [12, 13], Cause-Effect Chain Analysis (CECA) [4, 10], and others, such as the OTMS Network of Problems [14] or the Situational Analysis [15].

Additionally, the problem definition can be performed using other TRIZ-related methods. For example, in the Inventive Design Methodology (IDM) [8], developed by INSA Strasbourg, the analysis of the initial situation is performed by searching for the known problems, the partial solutions, and the cause-effect relationships, which are represented as a problem graph.

However, the reports on the application of these methods in the industrial practice are relatively rare. The paper [18] lists TRIZ tools used in more than 200 industrial case studies, which were presented in the TRIZ-Journal and Proceedings of the ETRIA Conferences. The problem definition tools are at the bottom of the list with the frequency-of-mention of 16% for TRIZ Function Analysis and 13% for the System Operator. The industrial reports or publications about the problem analysis with TRIZ in mechatronics [19, 20] are also rare.

One of the main drawbacks of the existing methods is not being self-explanatory, hence these methods require a systematic application experience. If designers try to apply a tool they use too seldom, the risk of mistakes resulting in wrong or incomplete problem definition or in unacceptable time expenditures is expected to be rather high. In such situations, the correctness of problem formulation often depends on intuition and personal experience of engineers.

Apart from the TRIZ methods mentioned above, the analysis of the initial situation can also be performed using common functional analysis approaches, known from the Value Analysis/Value Engineering [21], such as APTE method or the SysML requirement diagram [22], and others.

2.1 Identification of Contradictions

The TRIZ methodology postulates that the resolving of contradictions leads to strong ideas for inventive solutions. Therefore, the step that involves the identification or extraction of engineering contradictions belongs to the main task of the problem analysis. In accordance to the logic of the inventive algorithm ARIZ, the problem analysis results in the identification of engineering contradictions and in the formulation of corresponding physical contradictions [5]. The engineering contradiction is defined as the situation in which the improvement of one parameter implies a deterioration of one or more other parameters within a system. The physical contradiction is a situation in which one parameter of the system should have diametrically opposite values in order to meet the contrary demands to a system. In spite of the fact that the inventive algorithm ARIZ allows comprehensive identification of engineering and physical contradictions [17], the further development of TRIZ has led to the development of new analytical techniques, such as Cause Effect Chain Analysis (CECA), Root-Conflict Analysis (RCA+) [10, 11], and Network of Contradictions Analysis [15].

The Cause Effect Chain Analysis (CECA) supported with corresponding diagrams is one of the most well-known TRIZ tools for identification of engineering contradictions. Due to its high flexibility, it can be applied to a variety of problems of differing nature, and its results presented as a diagram are easy to communicate [10]. CECA helps to identify the key negative effect or disadvantage of the analyzed system and to build cause-effect chains. Even if CECA is easy to learn and use, in the practice it is not always easy to interpret its findings in order to formulate contradictions [10].

The Root-Conflict Analysis (RCA+), originally developed by V. Souchkov [11, 23] extends CECA with the claim of complete identification and ranking of all contradictions. The Root-Conflict Analysis uses a technique of top-down decomposition of an inventive problem formulated in terms of a negative effects to a tree of interrelated contradiction causes and their negative and positive effects.

An efficient, correct, and comprehensive application of CECA or RCA+ should be based on a preceding Component and Function Analysis of the engineering system. In the case of complex interdisciplinary systems, this requirement leads to considerable time expenditures as the application of CECA and RCA+ in mechatronics can result in extremely complex diagrams. In particular, when both methods are applied by engineers without profound TRIZ skills, there is a risk of simplification of multidisciplinary contexts in a mechatronic system, which can result in overlooked or wrongly understood contradictions.

Moreover, with the complexity of mechatronic systems increasing, there is a danger of diverse interpretations of a problem situation by different persons. Our observations in the application of CECA or RCA+ in student classes (mechatronics and mechanical engineering) demonstrate a high diversity of results if several groups of students have to analyze the same problem. Thus, the main focus of this working paper concentrates on the enhancement of reliability and repeatability of the contradiction identification in interdisciplinary engineering systems.

3 Proposed Approach for Problem Definition and Identification of Contradictions

The objective of the proposed approach for the problem definition and the identification of contradictions is to compensate the disadvantages of existing analytical TRIZ tools described above. It starts with a fuzzy inventive situation, where a change is needed and a disadvantage or a negative effect are already known but have not been analyzed. The identification of the innovation tasks, market demands, and new technologies is not a part of the method and should be performed separately.

The approach also does not replace the CECA or RCA+ methods, but it should close the methodical gap between the initial fuzzy problem situation and the final complete identification and ranking of contradictions, which are achieved with RCA+. First and foremost, it should help engineers, designers, and students without an in-depth knowledge in TRIZ methodology to define a multidisciplinary problem in terms of contradictions easily, fast and correctly.

Table 2 shows the general procedure of the proposed approach consisting of five steps, explained in the following paragraphs.

3.1 *Component Analysis and System Operator*

Considering a fuzzy initial inventive situation with a formulated improvement need and a negative effect or a disadvantage as the input data, the first step of the approach is to clarify and specify the objectives for the problem solving or design process. The Component Analysis and System Operator (multi-screen analysis) define the following aspects:

1. Main and complementary functions of the system, and if clarified, the key disadvantage or negative effect to be eliminated.

Table 2 The general procedure of the approach for interdisciplinary problem definition

Initial situation	Fuzzy inventive situation: need, disadvantage or negative effect is known but not analyzed
Step 1	1.1. Component analysis[a] 1.2. System operator (optionally)
Step 2	2.1. Circle system diagram[a] 2.2. Conflicting Pairs matrix (optionally)
Step 3	3.1. Essential function analysis[a] 3.2. Clarification of the Step 2 (optionally)
Step 4	4.1. Identification of key contradictions[a] 4.2. Ranking of contradictions (optionally)
Step 5 (optional)	5.1. Control by use of cause-effect-matrix CEM 5.2. Control by use RCA+ or CECA diagrams

[a]Mandatory steps

2. All essential components (sub-systems) of the mechatronic system; in order to identify all relevant contradictions on the multidisciplinary level. The pre-defined set of sub-systems reflects the typical structure of a mechatronic product: the basic mechanical structure, actuators, energy supply, sensors, control unit, software, information and data processor, mechanical, electrical and human interfaces, etc.
3. Optionally, the System Operator can be additionally used to compare the mechatronic system, including its sub-systems and the corresponding super-system, in its current state with its previous generations and with potential future forecasts as presented in Table 3.

Future forecast with the System Operator can be noticeably improved with the TRIZ patterns of technical evolution [17], which enable to describe the properties of a future mechatronic system and sub-systems in a more detailed way:

1. Increasing the adaptability
2. Increasing the controllability of fields
3. Increasing the interaction area
4. Co-ordination of the system's rhythms
5. Raising the degree of automation
6. Miniaturization
7. Transition to a bi-, poly-, and super-system.

As illustrated in Table 4, each evolution pattern outlines several possible development levels of technical or technological evolution. However, not all patterns can

Table 3 Component analysis including the System Operator

Super-system	…	Current super-system	…?
System	…	**Mechatronic system**	…?
Sub-systems	…	1. Basic structure	…?
	…	2. Actuator(s)	…?
	…	3. Control unit	…?
	…	4. Software	…?
	…	…	…
	earlier generation	*present state*	*future forecast*

Table 4 Example of TRIZ evolution pattern for application in the System Operator for analyzing mechatronic problems

Level of development	Pattern 5. Raising the Degree of Automation System or sub-system with…
1 (20%)	… manual control
2 (40%)	… fixed program control
3 (60%)	… stationary feedback control
4 (80%)	… adaptive feedback control and artificial intelligence
5 (100%)	… self-development and self-reproduction

be applied for each component of the system. Therefore, experienced designers have to combine an appropriate evolution pattern with the chosen system components to be analyzed in order to reduce their time expenditures.

3.2 Circle System Diagram

Using the information obtained in the previous step, a simple visualization method called Circle System Diagram, introduced in [24], can help to check and illustrate all possible critical interactions between system components and/or elements of environment, which have to be placed in a circle first at the same distance from each other. Figure 1 demonstrates an example of a circle diagram, where critical (negative) interactions between components are numbered and represented as arrows. The description of these interactions can be documented separately or directly in the diagram. The user can also apply the interactions types known from the Substance-Field Analysis [5]:

Useful action or effect:
Insufficient action or effect:
Excessive action or effect:
Harmful action or effect:
Unspecified interaction:

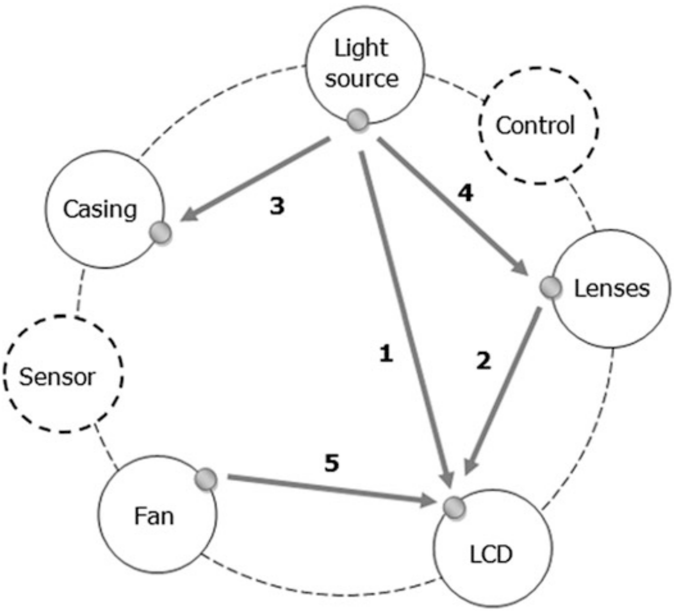

Fig. 1 Example of the Circle System Diagram with identified problem-relevant interactions between the system components

The time-saving advantage of the Circle Diagram is that any additional component, for example, a sensor or a control (Fig. 1) can be added to the circle without changing already existing interactions. The diagram works as a creative trigger, helping to identify possible interactions and conflicts within a system on one hand and checking if any relevant components are missing on the other hand. An example in Fig. 1 shows five identified interactions between the system components of a liquid crystal display (LCD) multimedia projector [17].

A systematic check of all possible interactions within a system can be optionally accomplished by using the conflicting pair matrix with a pairwise comparison of all system components [17]. Each interaction can be responsible for one or more engineering contradictions, which have to be identified and formulated in the next steps.

3.3 *Essential Function Analysis*

This step has an objective to accomplish the Circle System Diagram with a finite number of positive functions and undesirable properties in the system, which are relevant or essential for the problem situation as it was understood until this point. To perform this step, engineers should assign to each sub-system, if applicable, the following:

- positive effects or useful functions (P)
- negative effects or undesired properties (N)and to identify, if possible:
- a combination of positive and negative effects (P + N) within one sub-system or between sub-systems.

Such analysis often adds additional information to the understanding of the initial problem situation, which has to be documented in the Circle System Diagram on the previous step. Consequently, the reliability of the problem formulation process is also increased.

3.3.1 Identification of Key Contradictions

The combination of positive and negative effects (P + N) within one sub-system allows to identify monodisciplinary contradictions (only mechanical, only electrical, etc.). In the example, presented in Table 5, the *high velocity* of robot kinematic structure (positive effect) leads to a *smaller reachable workspace* (negative effect).

The combination of positive and negative effects (P + N) between different sub-systems helps to extract interdisciplinary contradictions. For example, the *high velocity* of the kinematic structure requires non-standard *complex transformation algorithms* to be realized in the robot control.

Thus, a list of engineering contradictions can be identified for a further ranking and selection of the key contradictions, which as a rule depend on the main demand

Table 5 Positive and negative effects of an industrial robot with parallel kinematic structure (fragment)

	Positive effects	Negative effects
Robot control system	– Control of actuators or axes – Definition of end-effector path – Communication with peripheral devices . . .	– Path deviations – *Complex transformation algorithms (N)*[a] – . . .
Parallel kinematic structure	– *High velocity (P)*[a] – High accuracy – Low moving structure weight – ...	– Difficult to control as one actuator moves more than one axis – *Smaller workspace* – . . .

[a]Example of interdisciplinary contradiction

or need formulated in the initial situation. The engineers often select the key contradiction intuitively on the basis of their understanding of the situation or in accordance with pre-defined general product development goals of the company.

The key contradictions can be recognized as those with the help of criteria known from the Root-Conflict Analysis RCA+ [11, 23]:

1. Comparative ranking of independent contradictions: the contradiction with the greatest contribution to the problem can be selected.
2. Ranking of contradiction chains: a so-called root-contradiction can be selected as a contradiction at the beginning of the chain if the resolving of the root contradiction leads to the elimination of the resulting contradictions.
3. Heuristic ideality-based ranking of dependent contradictions: a contradiction with a minimum number of involved components of the system or super-system can be selected from two or more correlated contradictions.
4. Constrain-based ranking of dependent contradictions: a contradiction with components that are easy to modify or influence can be selected.

3.3.2 Control Step

If the choice of criteria supporting the extraction of the key contradiction seems to be difficult at this stage, engineers can check the Cause-Effect-Matrix (CEM) or/and run the complete Root-Conflict Analysis explained in detail in RCA+ guide [23].

Contrary to the RCA+, the Cause-Effect-Matrix (CEM) is an easy-to-use method proposed by the authors at the Offenburg University, especially for the analysis of interdisciplinary problems in mechatronics and process engineering. The CEM combines a simple ideation technique MATChEM-IB known in the Substance-Field Analysis [25] with the cause-effect-consequence observations in a problem situation. Table 6 explains the fast CEM method, which helps to identify interdisciplinary root-cause chains and can support engineers during the whole problem formulation process.

Table 6 Illustration of the Cause-Effect-Matrix (CEM) for the identification of interdisciplinary contradictions

Negative ***Consequences***									
...									
Negative ***Effect*** *(level 1)*									
Causes *of negative effect*									
Fields	1. Mechanical	2. Acoustic	3. Thermal	4. Chemical	5. Electrical	6. Magnetic	7. Intermolecular	8. Information	9. Biological, Human

Supplementary to the interpretation of MATChEM-IB presented in [25], we recommend introducing here the additional *information* field and the influence of *human operator* in the field positions 8 and 9.

For example, starting with mechanical cause of a negative effect at the bottom level, an engineer can easily see and document the negative electrical effect that may further lead to a thermal problem (overheating) as a consequence. Different cause-effect-consequence chains can be checked rapidly top-down or vice versa in this way.

4 Conclusions and Research Perspectives

The proposed approach for problem definition was verified by a preliminary experiment conducted at the Offenburg University of Applied Sciences. The results confirm the expectation that these simple problem formulation techniques definitely improve the quality of problem definition as they helped fourth semester mechanical engineering students to identify contradictions in initially unknown mechatronic problems. The students worked in groups of 2–6 persons and were able after the introductory 30-minute explanation of the approach to perform the mandatory steps of the method for interdisciplinary problem definition 1.1, 2.1, 3.1 and partially 4.1 within 60 min and to identify on average 2–3 relevant engineering contradictions. The optional auxiliary steps 1.2, 2.2, 3.2, and 4.2 were not applied as they are recommended for specialists with TRIZ experience.

Even if this experiment cannot be considered statistically significant, its results have motivated the authors to organize an international experiment in problem formulation in order to scientifically analyze and evaluate the efficiency of TRIZ methods in systematic problem definition by engineering students.

The proposed working techniques, such as the System Circle Diagram, the Enhancement of the System Operator with the Evolution Patterns, the extension of the MATChEM-IB operator with Information field and Human interactions, and its application for building the Cause-Effect-Matrix (CEM), may be also incorporated in other approaches or used separately during the problem formulation process.

The future research should also focus on the automation of contradiction ranking, on advanced methods for the identification of physical contradictions, as well as on new approaches for resolving engineering contradictions in interdisciplinary engineering fields such as mechatronics.

The authors wish to suggest that engineering educators need to consider including fast systematic problem formulation techniques in engineering studies.

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