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

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Content

Part 1 – Practitioners papers

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TRIZ Methodology Adapted to a Dynamic System Projected Acoustic Study

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Abstract

Nowadays, domestic appliances manufacturers launch products with a special care taken on the sound quality since the early design stages. Indeed, the sound emitted by a product can give a subjective feeling of robustness, reliability, and good finishing to users. The usual approach consists in, first determining the sound target linking objective psychoacoustic parameters, characterizing a sound and subjective users' impression on similar sounds of the product by setting hearing tests.
Then, an original acoustic-oriented design approach called Dynamic System Projected Acoustics (DSPA) is adopted during the design product stage. It aims at selecting and laying out the different elements of the product in order to reach the sound target, given their sound and vibration characteristics. Generally, changes to apply on the product to fit with the sound target are pointed out by the designer based on his own experiences of sound product design.

This current paper will propose an evaluation of changes or adaptation to make to an S-field type model coupled to a "Local Ideal Final Result" notion in order to build a systematic approach for an application to a DSPA study. The established procedure used in this present study aims at, first, identifying principal components or groups involved in the field of the research problem and then, describing an adapted process of problem solving derived from TRIZ to generate solutions. Finally, the procedure involving TRIZ approach applied to an acoustic problem implementing airborne and structure-borne phenomena will be put to the test.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: S-field, Sound Quality; Acoustic-Oriented Design Approach; Systematic Approach

1. Context

1.1. Sound quality study

Sound quality studies are recent and have begun in the automotive field. It has spread to the domestic appliances subsequently. The goal of such a study is to determine the elements in a sound, creating specific feelings for an object in particular.

Currently a sound quality study is organized in four steps: the first step consists in building up a sound database gathering real or modified sound defining the sound scope and noise elements on which listeners are asked to give their opinion on. Then, listening tests will allow the experimenter the access to the sound quality perception of the listeners. A statistical method of data processing is used to analyze the Listeners test results. The last step aims at finding the link between subjective and objective elements. It correlates results from the listening test analysis with psychoacoustic parameters.

The sound target of the appliance can be obtained at the completion of the sound quality study.

1.2. DSPA approach

Studies have been carried out at LMVA (*Laboratoire de Mécanique Vibatoire et d'Acoustique*) for more than 30 years in sound quality and have been continuously promoting this approach [8], [9], [10].

It is an innovative approach of designing products that has the ambition to foresee the sound of the working appliance during the design stage and thus well before the fabrication of prototypes. It consists in calculating or measuring frequency and time characteristics given sound and vibrations from each dynamic elements of a mechanical system then bring in all vibration and airborne ways of transmission that propagate energy of the source to user's ear.

To define the diagram of noise, vibration and harshness (NVH) interaction a system has to be studied intensively. This study requires numerous noise and vibration notions and supposes a good understanding of complex sound generation mechanisms. The resulting diagram will contain NHV characteristics of sources and transmissions characteristics, which can be frequency spectra of sound pressure or acceleration, transfer functions and psychoacoustic parameters.

Knowing the sound target and the sound of the current appliance, it is then possible to identify and quantify the psychoacoustic parameters to be changed in order to reach the sound target.

The next action is to detect, among the elements in the diagram of interaction, important contributors to the variation of psychoacoustic parameters to modify. The complete path of sound transmission needs to be taken into account to determine the effect of the previously identified contributors on the psychoacoustic parameter

The last step consists of determining changes to make to the sources or transmission ways in order to obtain the expected level for the identified psychoacoustic parameter

Fig. 1 Hybrid Boiler (heat pump on the left, gas boiler on right)

1.3. Scope of application

The appliance studied here is a hybrid boiler combining a heat pump and a gas burner. It was designed without prior consideration of the acoustic performances. The noise level is higher than the regulation specification for putting the appliance in a living space. Moreover, the sound is received as disturbing by users. The DSPA is a solution to acoustic design problem as it integrates an acoustic study since the early stages of appliance design.

2. Analogies between DSPA approach and TRIZ methodology

The idea of associating TRIZ methodology with other methodologies was anticipated by Cavallucci [11]. Bridges between TRIZ inventive methodology and others design methodologies were investigated [12]. More recently, TRIZ was combined with the business strategy simulation Blue Ocean Strategy [13]. Hybridization of TRIZ tools with various domains like biomimetic is also well-known [14] [15].

DSPA is a design methodology with emphasis on NVH optimisation. Like the TRIZ methodology, the DSPA approach follows a solving diagram based on a step of modeling of the problem leading to a model of solution. The latter is interpreted to find solutions of the initially stated problem (fig. 2).

In the DSPA approach, two initial studies are managed simultaneously. The first aims at finding the ideal sound the appliance could make in term of sound pleasure, sound acceptance or sound expectation as experienced by the users. The approach employed here follows the steps of a sound quality study, explained in paragraph 1.1. It results in the determination of the sound target of the appliance. The sound quality study can be considered as a systematic approach to obtain the ideal sound of a specific appliance.

The second study will focus on the characterization of the current appliance using psychoacoustic parameters and knowledge in ear signal processing. It can be divided in two vibro-acoustic sub-elements: mechanical systems implemented in the appliance and their fitting. The concept is a snapshot of the contribution of components to the signal entering the ear. This can take the form of a diagram of components, parts or elements and their interaction contributing to the perceived signal.

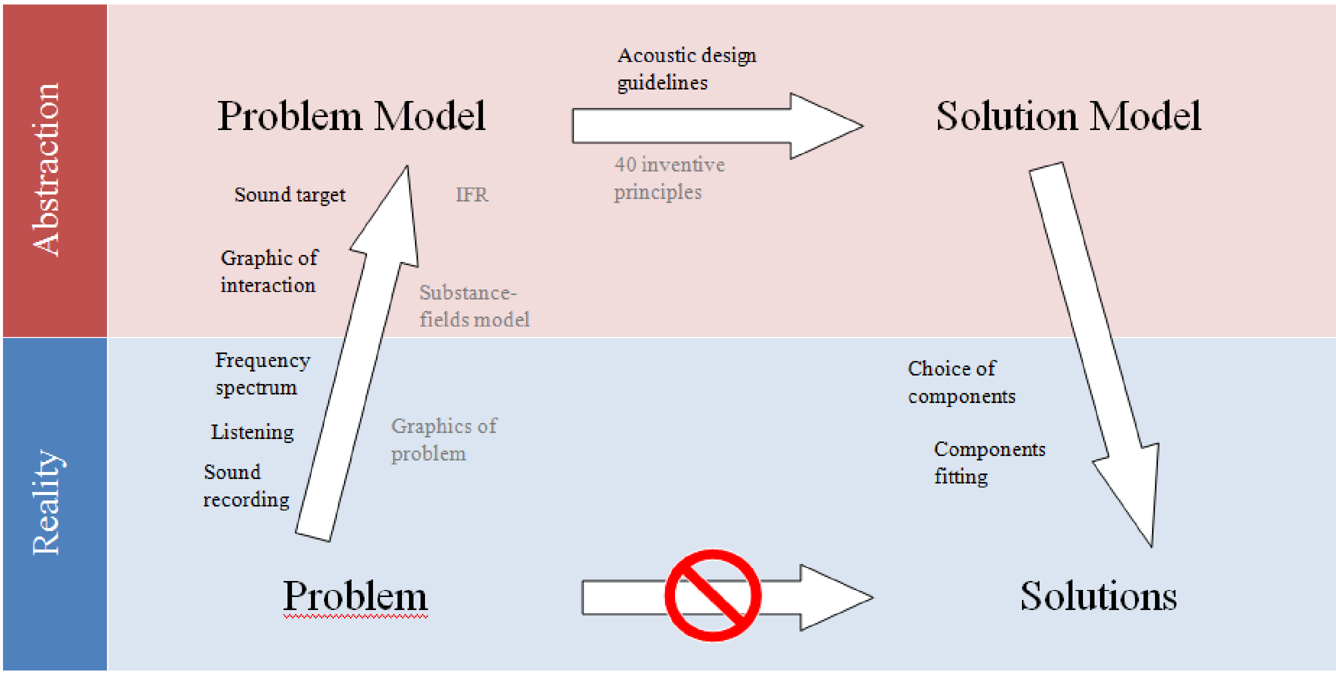

Fig. 1 TRIZ Diagram Process Analogy with DSPA Approach

Some output elements from the DSPA approach are similar to some analyzing tools used in TRIZ methodology. Indeed, the sound target can be considered as the IFR. And the graphic of interaction in terms of NHV is similar to a modified substance-fields system. Resolution tools in TRIZ methodology are replaced by well-known acoustic design guidelines.

As it can be noticed, DSPA approach is following the same principles and uses similar tools as TRIZ methodology. However, DSPA is not a problem solving methodology but a concept of designing an appliance turned toward hearing perception.

3. Substance-field model adaptation to DSPA approach

The usual substance-fields model is a tool and a graphical representation for problem modeling. Numerous studies showed the sub-field system can evolve but they mainly deal with modifications of standards solutions [16] and not the sub-field diagram itself. The latter is usually centered on the entire interactions between substances. But the adapted substance-fields system focuses on the analysis of a physical phenomenon, the sound emitted by the appliance. Only the elements contributing to the overall sound of the appliance are mentioned in the system. The employed approach attempts to highlight principal elements of the system to be changed in order to reach the sound target. The overall diagram represents all sources and interaction between components. An example is given (fig. 3).

4. Evolution of the substance-fields model

The diagram used for the DSPA approach shows some differences from a usual sub-field system. The actual system representing the appliance is complex as there are many interaction effects between the different components on the acoustic and vibratory behavior. Generally there is not a single solution. Several combinations of changes can lead to the same sound target. The final solution will be taken according to the limits defined by cost, production limitations, appliance dimensions... In order to determine the sources and transmission ways involved in the sound characteristics to be changed to reach the sound target, NVH sources and transmissions ways need to be characterized and quantified with acoustical, vibratory and psychoacoustic quantities. But the standard substance-field diagram does not integrate these parameters. Consequently, to bring out and prioritize actions and solutions, the modified substance-field diagram employed here will associate a frequency spectrum, a sound or vibration level, a transfer function to elements of the diagram. Thus, the noise contribution of these elements on the signal reaching our ear can be predicted. In Fig. 3, this added information does not appear. With the new sub-field diagram, it is theoretically possible to determine which sources and transmission ways are the optimal elements to work on in order to reach the sound target and to evaluate the consequences on the sound frequency spectrum in output. Unlike the adapted version, the usual sub-field does not allow a prioritization of actions and cannot predict the changes on the output, i.e. the sound frequency spectrum in the current application.

The interactions cannot be predetermined as being "harmful", "insufficient", "excessive" or "useful" in advance. All depends on the sound target for a given diagram.

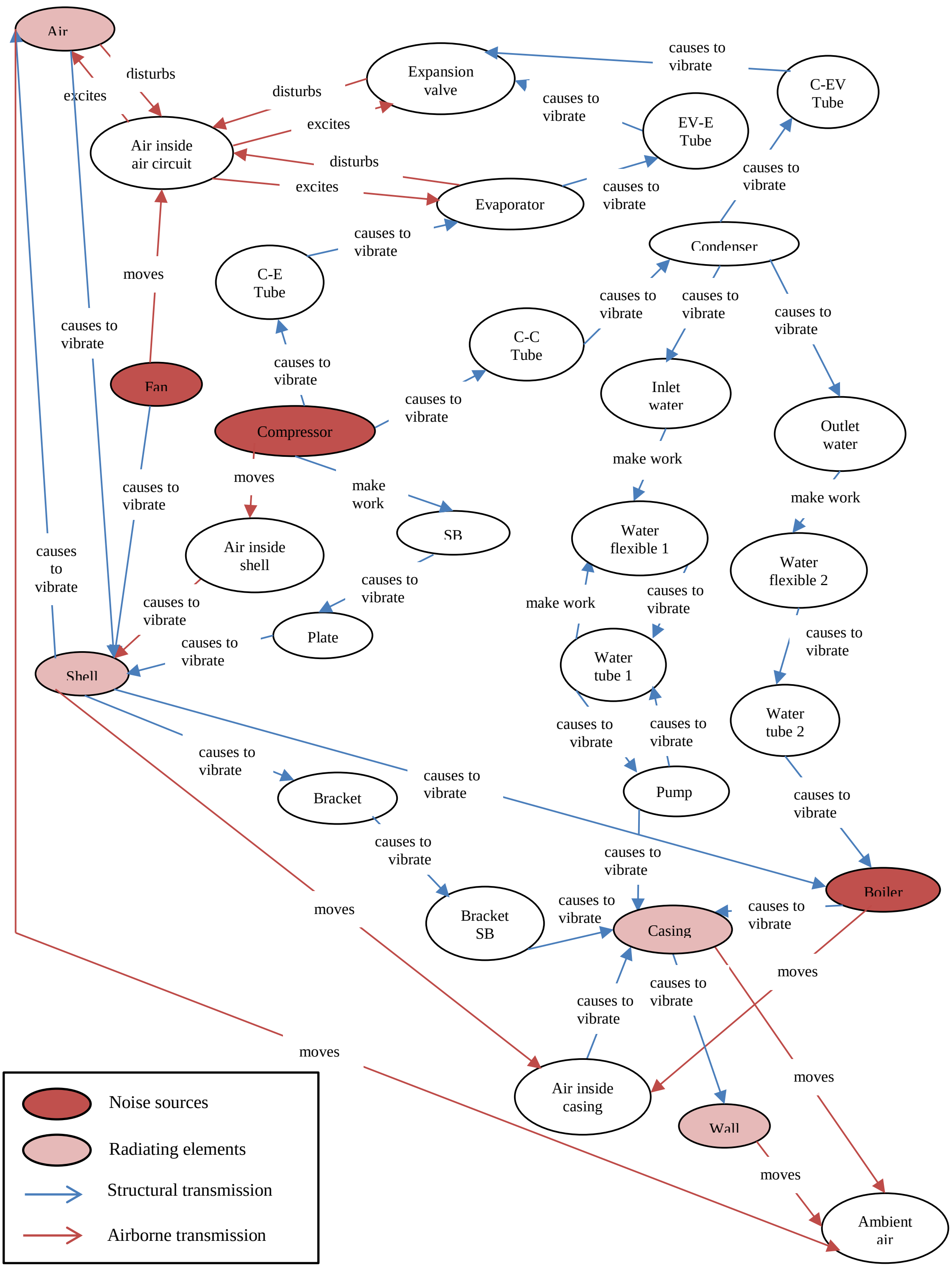

Fig. 2 Modified Sub-field System Adapted to DSPA Approach

4.1. Complete model

Theoretically, it is possible to determine which element(s) to act on to design an appliance making an expected sound. In some cases the difficulty lies in the impossibility to determine the NVH characteristics of elements because of low efficiency between time/cost invested and knowledge on the output.

If one of all the elements is unknown, the ordered influence of the elements acting on a psychoacoustic parameter of the overall sound is made impossible.

The complete modified substance-field model cannot be fully filled in the application case because of the complexity of interactions. Noise and vibration experts are able to distinguish the elements to act upon and know which changes to make to reach the IRF without a complete sub-field system. They also use their experiences to cut down and simplify NHV interaction.

4.2. Simplified models

A succession of different level of simplified substance-field model is investigated from more to less complete models.

4.2.1. Sources leveling

Lots of complex interactions are identified in fig.3. To make it less difficult to read, the diagram was modified so that elements are classified according to the level to cross before its sound makes it to the ear which can be seen as the ambient air.

But ordering the elements will not change the missing knowledge needed to determine the components contributing significantly to a psychoacoustic parameter. The leveling of components as a simplification of the complete diagram of interaction cannot be used for the identification of sources.

4.2.2. Separation of sources

It has been noticed the difficulty to characterize all sources and ways of transmission. Naturally, the next action following the leveling of sources is to simplify and reduce the interaction. This supposes some assumptions are made. However, the simplification of the diagram of interaction can constitute suggestions of improvement or solutions. For instance, deleted interaction may mean the interaction should be suppressed. New layouts can stick out. For example, the contact between the compressor and the EPP shell is not necessary. The shell is only needed to define the air circuit and isolate thematically the cooled air. The physical link between the compressor and the shell should be suppressed to reduce the vibrations exciting the shell and consequently, the radiated sound level of the shell.

5. Conclusion/Further studies

In this present study, the similarities between the DSPA approach and TRIZ methodology have been brought to light despite the differences in the scope and goal of application of both methods. TRIZ is used for solving problems while DSPA is a new design approach oriented in NVH domain. Since DSPA tries to combine a mechanical design problem with a care for auditory perception, it may be transposed to studies on others senses.

An adapted sub-field with a quantitative characterization of each element (substances and fields) was employed in this present study. Contrary to the standard sub-field, the new version can prioritize solutions and evaluate changes in output. An attempt was made to create a systematic approach in order to identify, prioritize and evaluate the contribution of all ways contributing to the characterization of the signal perceived by the ear in a form of a diagram of interaction. Theoretically, the approach works but practically, the diagram of interaction is too complex in the selected example. To validate the approach, it may be interesting to try it on a scaled-down scope or a simpler appliance.

Another study may be about the use of the approach described above in order to characterize contradictions to deal with in more precise levels of description (nearer of physical phenomena). Afterwards, the study follows a classic TRIZ process (define model of problem, bring out technical and physical contradictions, find model of solutions).

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The transition from the Function Analysis to the TRIZ solving tools

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Abstract

After setting up of the function model, which is a part of modern TRIZ, we often run into the problem of selection of right TRIZ tools. There are many relationships described - functions in the function model. However, recommendations for further actions are only in the form of a verbal description. Also in known versions of ARIZ used at present we encounter difficulties of technical contradiction formulations and detection of conflicting pair that are not quite obvious and are often various.
For example, in ARIZ 82 initially the conflicting pairs are chosen and then the technical contradiction is written, in ARIZ 85C it is the opposite, the technical contradiction is written and then the conflicting pair is shown, in ARIZ 91 the technical contradiction is formulated on the basis of the main functions and negative effect. Explanation of contradictions in the RCA + based on negative effect does not fully use the results obtained from the function analysis.
Therefore, the authors of this article tried to outline more detailed approach to clarify the conflicting pair coming out directly from the function model and ways of selecting TRIZ solving tools according to the conflict type. The approach will be accompanied by graphic illustration and example for clarification.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: Function model, conflicting pairs, disadvantage, TRIZ tools, ARIZ ;

1. Introduction

ARIZ 85C is probably the most famous version of the algorithm published by Altshuller [1]. This version is used till today by a number of users. There are classical tools included in this version such as Inventive Principles for resolving Technical Contradictions, Principles for Physical Contradictions elimination, Su-Field Analysis, Physical Effects. ARIZ 85C starts to work with conflicting pair from the first step without considering the more detailed explanation of how this pair have been obtained from the system. At the same time technical systems are usually the complex set of components and their interactions.

Besides, Function Analysis (FA) operates within TRIZ since Gerasimova, Litvin [2]. FA procedures were included in ARIZ 91, but only in verbal form. Use of interactions from FA is performed in Devojno [3] and Cameron [4] but especially in relation to the Standards of Su-Field analysis. Procedure GEN3 [5] classifies FA in a long chain of analytical methods that result in finding a key task, which can be time consuming for many users. The authors raised the question:

- Would it be possible to better use FA advantages directly with links to ARIZ 85C and its tools?
- Would it be possible to create algorithm for the process of transition from FA to ARIZ?

2. Theory

Function analysis is the basis for the analysis of a complex system with advantages. It describes the functions of the system components to show their disadvantages.

A typical FA model - see Figure 1- includes a number of functions that are visible in a graphical form which are described not only as a useful interactions (solid thin line), but also disadvantages (zigzag line, bold solid line, dashed line).

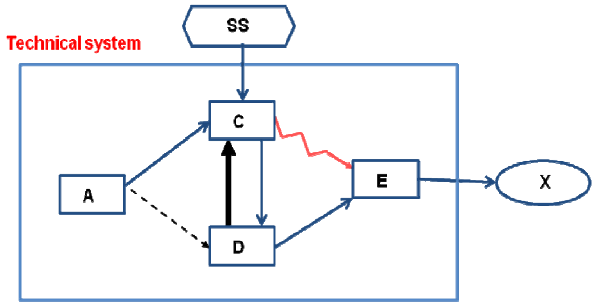
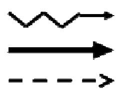


Fig. 1 - Typical FA model

Disadvantages are identified by type of arrows:
a) harmful interaction
b) excessive interaction
c) insufficient interaction



Removing of these disadvantages means to choose a given interaction and to solve problems associated with it. The solution can take place at several levels:

- By use of classical engineering approach that can apply known solutions (this is not subject of our research)
- By the application of engineering approach that show conflict where the removal of a specific disadvantage in one function causes disadvantage in another. Therefore, it creates conflicting pair (this is the case of our research)
- If it is not known which classical engineering solutions can be used, it is possible then to use Standards of Su-Fields Analysis according to type of interaction.

However, It is recommended to try to compile a conflicting pair before application of Standards, because resolving of the particular contradiction can solve the problem more efficiently.

3. Compilation of a conflicting pair from FA model

By selection of disadvantage from presented FA model of technical system the conflicting pair not yet arises. It arises only after engineering approach is applied that try to seek the remedy of disadvantage. Such procedures of application of engineering approach can be represented graphically -see Figure 2.

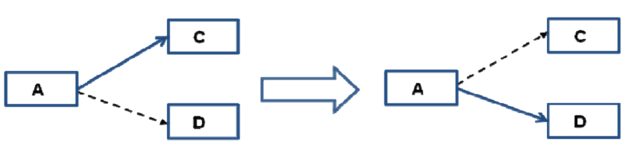


Fig. 2 - Graphical representation of conflicting pairs

In an effort to remove the insufficient interaction between two components, interaction between neighbouring components is weaken. After, the right conflicting pair will arise which is then used in the step 1.3 of ARIZ 85C

These conflicting pairs arises only after the selection and transformation by a classical engineering approach.

If you cannot compile conflicting pairs, you can take the selected disadvantage and transfer it to the appropriate Standard of SU-Field Analysis according to the scheme - see Figure 3.

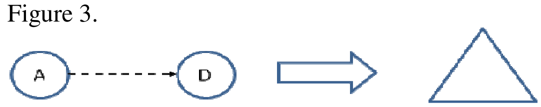


Fig. 3 - Transfer of conflicting pairs of FA model to Standard of SU-Field Analysis

4. Algorithm of transition from the FA to the TRIZ tools within ARIZ

The procedure of the algorithm is evident from following Figure 4.

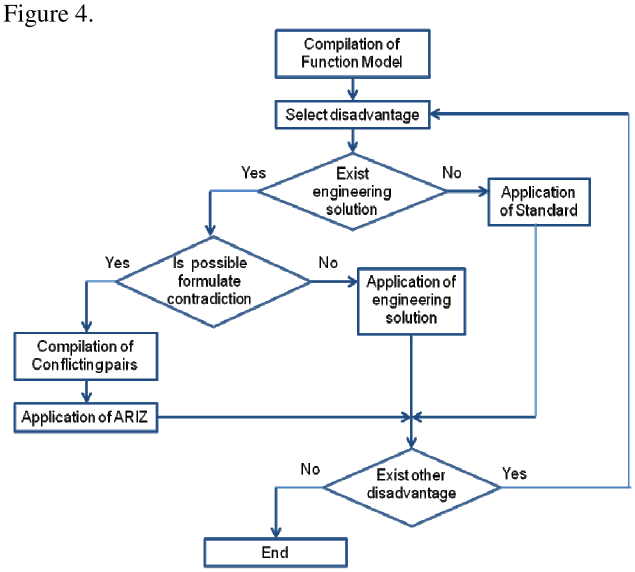


Fig. 4. - Diagram of the algorithm of the transition from the FA to selected tools of TRIZ/ARIZ

The algorithm can be applied to FA model of technical system, in which at least one disadvantage in terms of arrows indications a), b), c) is detected.

5. Case study of the algorithm application

Use of the algorithm will be demonstrated in case study of bulb filament.

Filament has several parts, which passes through the current and emits the light while Wolfram escapes - see Figure 5.

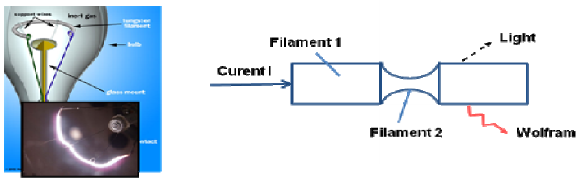


Fig. 5 - Schema of bulb filament

FA model of the technical system is created from these basis - see Figure 6.

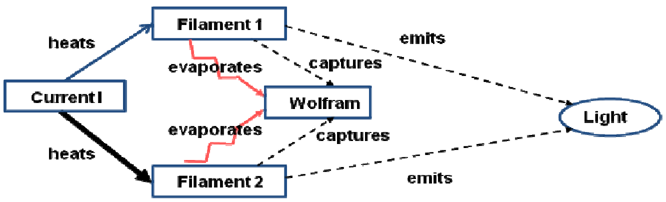


Fig. 6 - FA model of bulb filament

1. Excessive level of the function - heating of F1.
2. The harmful function - evaporates W from F1.
3. The harmful function - evaporates W from F2.
4. Insufficient level of the function - capturing W from F1
5. Insufficient level of the function - capturing W from F2
6. Insufficient level of the function - emits L from F1
7. Insufficient level of the function - emits L from F2

4.1. The selection of the tools according to the algorithm:

The selection according to the first disadvantage (heating of F1):

Reduction of the current level is a common way how to prevent overheating of F2. But this way it will cause the insufficient heating of F2 and therefore reduction of light emission - see Figure 7

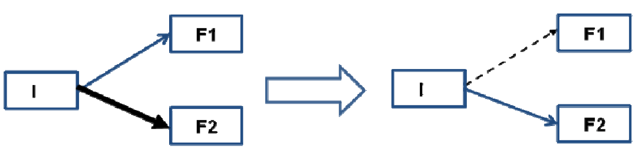


Fig. 7 - Schema of the transition from FA model to the conflicting pair at disadvantage 1 (heating F1)

The solution: sequential start of current level prevents overheating of F2.

The selection according to the disadvantages 2 and 3:

Reduction of filament temperature is a common way how to remove harmful function - evaporation of Wolfram. But this way will cause the additional reduction of light emission - see Figure 8.

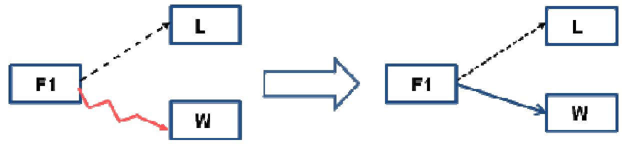


Fig. 8 - Schema of transition from FA model to the conflicting pair at disadvantage 2 and 3 (evaporation of W)

If we want to maintain temperature of heating filament, there is no known engineering solution and it is then necessary to transfer it to the appropriate Standard 2.1. of SU-Field Analysis - see Figure 9.

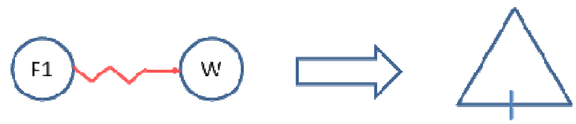


Fig. 9 - Schema of use of Standard 1.2 for disadvantage 2 and 3 (evaporation of W)

The solution: Halogen lamp, which returns Wolfram back to the filament at a higher temperature through decomposition of compounds WJ.

Analogous procedures can be used for disadvantages 4.,5. and 6.,7.

6. Conclusions

From the analysis of the process of the transition from FA to TRIZ / ARIZ tools mentioned above results the following statements:

- It is possible to select and formulate the conflicting pairs directly in relation to the FA model
- The process of transition from FA to TRIZ / ARIZ tools can be described by an algorithm
- It is possible to find more conflicting pairs by application of FA model than with the direct application of ARIZ 85C, therefore more improvements of given technical system in accordance with customer requirements can be achieved.
- It is recommended to compile the conflicting pair before an applications of standards, because resolution of the particular contradiction can solve problem more efficiently.
- The graphical representation of the process is better than just verbal presentation as shown in ARIZ 91

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Case Study: TRIZ-supported Development of an Allocation System for Sheet Metal Processing

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Abstract

This case study presents the new development of an allocation system by using TRIZ tools. The allocation of sheet metal parts for further treatment is currently done manually. The demand for decreasing station times to utilize the processing machine to its full capacity brought up the need for a partially automated allocation system. Because of the high requirements regarding process reliability, safety, robustness, maintainability and asset costs, a systematic approach using TRIZ tools was necessary for developing a successful solution.
The development process of the allocation system was systematically conducted using several TRIZ tools. The first step covers the clarification of the task, the customer requirements and specific company guidelines. Then analytical tools of TRIZ were used to structure the task and identify key problems and development obstacles. After that, TRIZ solution tools were utilized to develop ideas which were finally combined into a qualified, capable solution.
The presentation shows, how TRIZ tools sped up the process of task analysis, problem identification and solution generation significantly. The developed concept is currently in the feasibility and design phase, main secondary problems are as well tackled with TRIZ tools. Prototype testing and implementation is planned for later this year.

Peer-review under responsibility of The International Scientific Committee ETRIA.

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

1. Initial Situation

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

It was the company's target to speed up the development and solution finding process for development tasks and obstacles by using the TRIZ methodology.

For that reason TRIZ was used on different levels during this project:

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

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

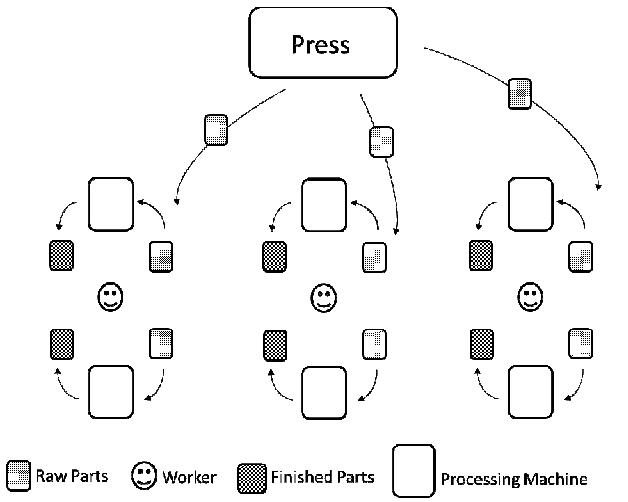

Fig. 1. Initial situation of the manufacturing process

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

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

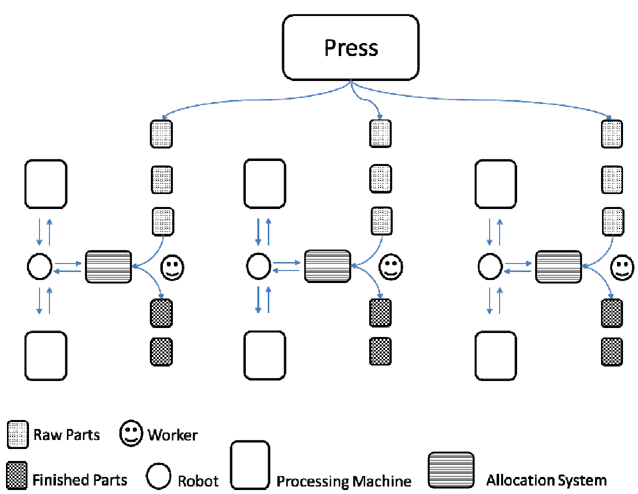

Fig. 2. Desired workflow with semi-automated Allocation System

1.1. Situation Clarification

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

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

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

1.1.1. First Step: System – Subsystems - Supersystems

In the first step of filling the 9 Screens the team looked at the current stage of development and the intended design of the allocation system (see Fig. 3). The system is allocation system, consisting of a guide, rack, lift, camera, control system and transport boxes. The supersystems identified were the upstream press, raw parts, finished parts, worker, robot and downstream processing machines.

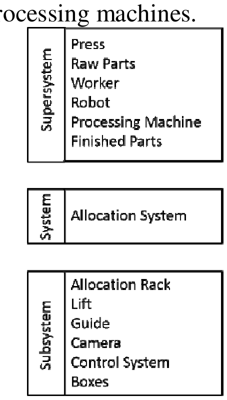

Fig. 3. System-Structure of the Allocation System

1.1.1.1. Functionality of the System

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

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

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

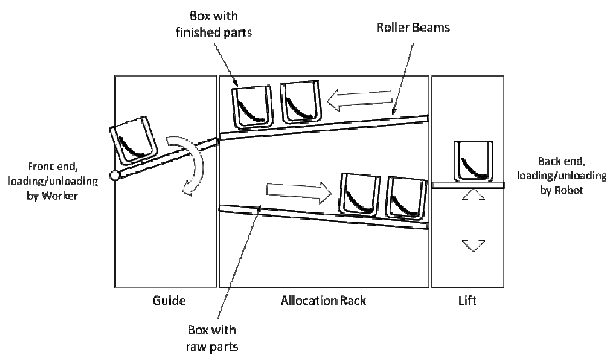

Fig. 4. Simplified representation of the Allocation System, first concept

1.1.2. Second Step: Past – Present - Future

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

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

Fig. 5. Past and Present System

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

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

Fig. 6. Multiscreen assessment of Allocation System

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

2. Problem Analysis

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

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

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

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

2.1. Function Model of the Allocation System

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

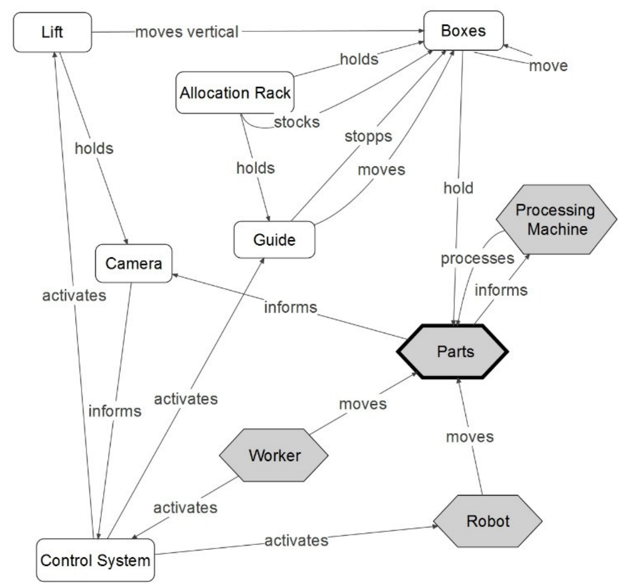

Fig. 7. Graphical Function Model of Allocation System

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

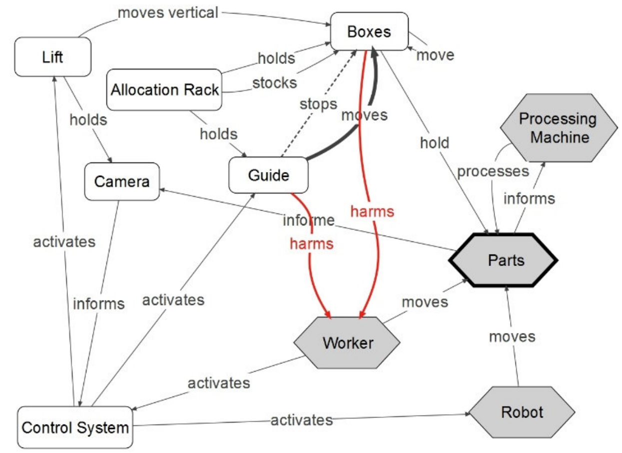

Fig. 8. Function Model with Function Disadvantages

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

1. Guide stops Boxes insufficiently
   This disadvantage depicts the situation that the boxes, due to their weight and the angular positioning of the guide, have a high velocity that leads to an abrupt impact. This impact generates noise and represents a potential threat to the worker.
2. Guide harms Worker
   The guide consists of moving parts to be able to direct the boxes into different levels of the allocation rack. These moving parts are positioned in the area where the worker has to load and unload parts. Therefor the threat of injury is given and has to be eliminated.
3. Boxes harm Worker
   As mentioned under 1. The boxes are able to hit the worker due to their kinetic energy. A hand can potentially be placed between parts of the guide and the moving box.
4. Guide moves Boxes excessively
   Due to the high angle of the guide the boxes are accelerated to a high velocity, leading to high kinetic energy and thus being a risk for the worker.

2.2. Cause-Effect-Chain Analysis

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

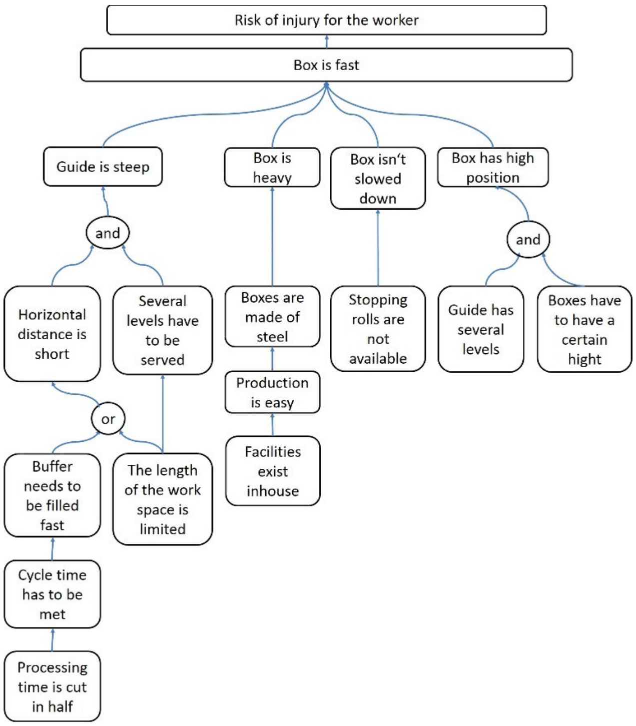

Fig. 9. Cause Effect Chain Analysis for Risk of Injury

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

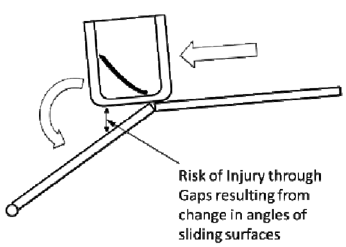

Fig. 10. "Operating Zone" where the problem occurs

3. Formulating Problem Models

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

3.1. Primary Problem: Worker's Health and Safety

According to the first design concept, the boxes containing the parts were designed to slide on roller beams through their own weight and the angular positioning of the guide and allocation rack levels. Preliminary tests showed that the boxes were really picking up speed along the length of the allocation rack. This high velocity poses a risk for the worker (see also CECA). So the use of boxes was questioned and several options were discussed.
Additionally, the use of a second lift instead of a guide on the front-end of the Allocation System was discussed to have a more controlled movement of the boxes and eliminating changes in sliding path angles (and eliminating gaps), thus reducing the risk of injury.
The thought process was supported by the concept of Ideality, always looking for possibilities of functions being carried out by "itself" or looking for the ideal system (e.g. the ideal box), that is performing the useful functions without being present physically [3] [5] [6].
Some of the contradictions formulated are shown below.

3.1.1. Engineering Contradictions resulting from using a brush belt conveyor

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

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

3.1.2. Engineering Contradictions regarding using Boxes and using Lifts

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

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

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

3.1.3. Physical Contradiction representing Worker Safety and Cycle Time

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

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

The boxes
should be moving fast to reach a short cycle time and
should be standing still to ensure a save work situation

First it was stated that the boxes need to be stopped or slowed down to increase worker safety. But this slowing down means an increased cycle time, which is unacceptable. Not shown is the inverted Engineering Contradiction, stating that if the boxes are sped up, the cycle time increases, but the worker's safety deteriorates.

The Physical Contradiction could easily be derived from this statement, enabling a focused idea generation around this inventive problem.

4. Solution Concepts

After the problem models were formulated, the idea generation phase was initiated. Using suggested Inventive Principles and Separation Principles, the initial concept of the allocation system was modified to overcome the contradictions coupled with the first draft.

4.1. Solution Concepts for Worker's Health and Safety

Guided by the TRIZ solution strategies and principles, several ideas were sparked and developed into the following concept:

By separating the need for fast moving boxes and still boxes in time, an enclosed solution was developed that only allows the worker to access the loading / unloading area when all moving parts have come to a full stop. The solution suggests a sliding door that is opened by a counterweight (ideally "opening itself") as soon as a box is ready to be loaded / unloaded. After the worker completed his step, he closes the sliding door, activating the Allocation System and allowing the boxes to move fast through the steep guide and allocation rack. This results in lower cycle times while eliminating the risk of injury. Another advantage of an enclosed system is, that noise can be effectively damped and no special dampers are necessary to reduce impact speed of the boxes.

As a second winning concept, the moving principle for the boxes was changed from sliding on roller beams to attaching rolls to the boxes themselves. In a first idea, rollers were suggested on the bottom of the boxes, but during the idea generation phase and the discussion this concept was changed to a roller-and-track system, where rollers are placed in the top corners of the boxes, which can then be hanged into a track system that is guiding the boxes throughout the allocation system.

This concept also enabled the elimination of a driven belt on the back-end of the allocation system which was before necessary to move the boxes in and out of the lift. The roller-and-rail system allows the boxes to move themselves into and out of the lift. Small gaps and angular changes in the track can easily be rolled over.

The roller-and-track system then has been optimized to be self-cleaning by using shaped rollers that run on guiding rails. Dust from the environment will first be significantly reduced by the casing of the enclosed system, additionally dust is very unlikely to settle on the rails.

5. Conclusions and next Steps

The support of the development project with TRIZ resulted in the intended advantages. The time invested for thoroughly analyzing the situation, identifying the major problems and focusing on root causes instead of symptoms paid off regarding several aspects:

1. The TRIZ-guided process opened eyes for the "real" problems and in which order to solve them. Previous decisions based on assumptions could be revised and corrected, saving time and proactively considering hidden or unspoken customer needs.
2. Especially the CECA and Function Analysis helped to uncover missing or contradicting information from the customer, which could then be included in the specifications and requirements management.
3. TRIZ brought up the right questions through its Ideality- and "Ideal System"-focused approach. As a result effective solutions were generated in a short amount of time. Consideration of the "Self-Principle" lead to sound design decisions that were robust, safe and cost effective.

Currently, the concept is detailed. Subsequent problems are if necessary also tackled with TRIZ tools. Tests of the roller-and-rail system are currently going on and the first prototype run is scheduled to be completed in the first half of 2014. The delivery of the first allocation system is planned for end of 2014.

Upcoming development tasks for future versions are already being identified, one of them being to decrease the overall length of the allocation system to reduce the occupied space on the shop floor. It is intended to establish TRIZ as an integral part of the development process of the company.

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

TRIZ DOCTOR: A Mobile Application for Learning TRIZ

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Abstract

This paper introduces a mobile application for learning TRIZ. TRIZ is undoubtedly one of the most popular methodologies for systematic problem solving. Therefore many universities and other educational institutions are now offering TRIZ classes for the purpose of enhancing creativity and problem solving skill. However, it is not easy to expect trainees to apply TRIZ for their own real problems beyond the level of learning something. Large amount of materials and less accessibility of data lead to this situation. In order to provide TRIZ tools handy, we have developed a mobile application named as TRIZ DOCTOR. The application includes TRIZ basic tools such as 40 inventive principles, separation principles and contradiction matrix. It enables trainees to learn TRIZ interactively and to use TRIZ tools even after the class anywhere anytime. It is illustrated that our application can be utilized as a good instrument for learning TRIZ.

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Keywords: Mobile application; TRIZ DOCTOR

1. Introduction

1.1. TRIZ education

Just look around your surroundings! You can find at least more than 1 slogans related with “INNOVATION”. We live in the world where marketplace realities are changing faster than new practical ideas can be generated. Therefore without continuous effort for being chosen by our customer, we may disappear as a duck takes to water. To keep up with what our competitors are doing and to meet customers’ ever-changing needs, the ability to generate creative ideas in a short space of time is indispensible.

Nowadays, TRIZ is treated as a systematic way of thinking which helps us overcome psychological inertia and solve contradictions. Therefore many universities and other educational institutions are now offering TRIZ classes for the purpose of enhancing creativity and problem solving skill [1].

However, it is not easy to expect trainees to remain more interested in TRIZ or to apply for solving real problems beyond the level of learning something. Large amount of materials and less accessibility of data lead to this situation.

1.2. Using mobile technology for education

Mobile devices like smartphones and tablets are now widely used for communication. It is designed to be extremely portable. Some mobile devices are more powerful, and they allow you to do many of the same things you can do with a desktop or laptop computer. There are so many approaches to use mobile technology for education [2-7]. M-learning, that is mobile learning, has received a lot of attention in recent years in the educational and instructional technology filed. It allows anyone to access information and learning materials from anywhere and at any time [2]. Analysis of several M-learning projects in Asia indicates that mobile phones impact educational outcomes by facilitating increased access [3]. EasyLexia is a mobile application developed for children who have learning difficulties [4]. Explora Mexico is a mobile application to learn Mexico’s Geography [5]. Mobile devices are overtaking the old fashioned desktop computers by providing flexible and easy access to information independent of time and place [6]. The availability of such convenient platforms brings about a new set of challenges for educator and trainers [7].

To get benefits of mobile technology for TRIZ tools, we have developed a mobile application named as TRIZ DOCTOR.

2. Experimental

2.1. Layout design of an application

In the glossary of TRIZ written by Valeri Souchkov, there are more than 300 terms related with TRIZ [8]. Besides classical TRIZ that was developed by Genlich S. Altshuller, many new related-tools are being developed. As we are aimed to develop a mobile application for TRIZ beginners, we set the range of the application as basic tools for idea generation: 40 inventive principles, a contradiction matrix and separation principles.

The 40 inventive principles are derived by extensive studies of numerous inventions. These can be used in combination with the contradiction matrix or independently. A contradiction matrix provides a systematic access to the most frequently used inventive principles to resolve a specific type of a technical contradiction. In the contradiction matrix, the specific type of a contradiction is selected by the pre-defined typical engineering parameters. Another basic tool of TRIZ are separation principles. They are particular methods of resolving two contradicting demands that is called as physical contradictions. Fig. 1 shows the main menu of the application. The menu is composed with 5 zones: 40 Inventive Principles, Contradiction Matrix, Separation Principles, Favorites and Idea Notes.

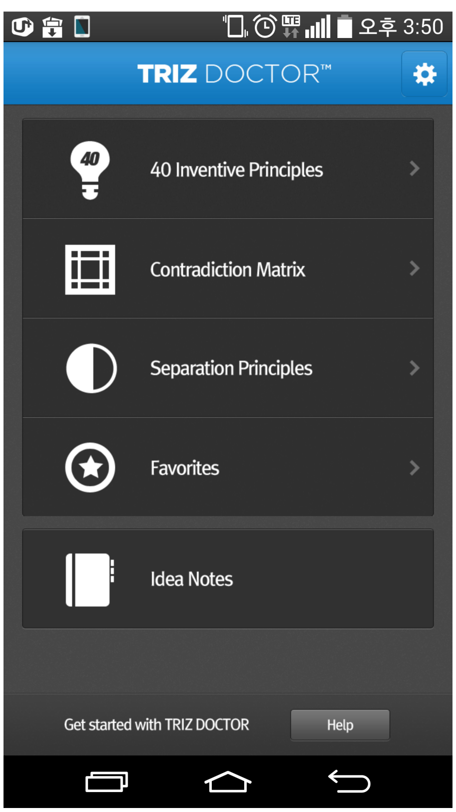
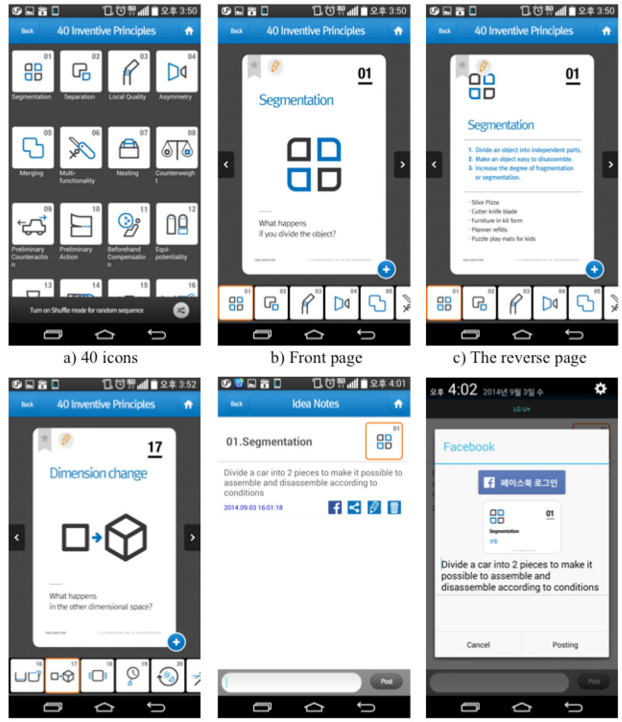


Fig. 1. Front page of an application.



a) 40 icons b) Front page c) The reverse page

d) Jumping to any cards e) Writing an idea note f) Sharing on Facebook

Fig. 2. Zone of 40 Inventive Principles.

'Favorites' zone is designed to collect and see only favorite principles in one space. 'Idea Notes' zone is one of the biggest advantages of using mobile application. A user can leave any message or ideas based on each principle and check anytime anywhere. Also, the idea notes can be easily shared with people using various mobile media such as Facebook, email, short message and so forth. You can also set the language as English and Korean. More languages will be supported later.

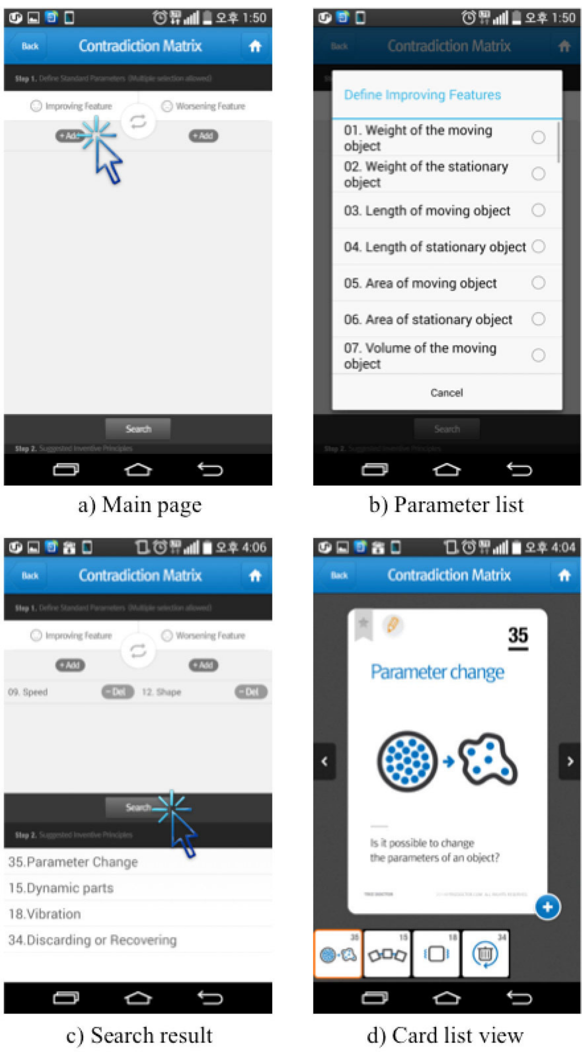
2.2. Zone of 40 Inventive Principles

Fig. 2 shows the screenshots of the 40 Inventive Principles zone. All layouts are designed based on minimalism for the simple and convenient use. A user can select an inventive principle from 40 pictograph icons of Fig. 2(a). These icons are specially designed using pictographs that represent the core essence of each inventive principle [9]. When any icon is clicked, an idea card is shown like Fig. 2(b). A user can see the next or previous card by paging action or clicking arrow buttons. On the front side of the card, the name of the specific principle, the associated pictograph and related question are listed. A user can see the reverse side by clicking the card image like Fig. 2(c). If you want to set the card as a favorite one, you click the icon at upper left corner. The navigation menu at the bottom enables jumping to any idea card quickly like Fig. 2(d). When you generate any idea based on the card, you can save using the idea note function like Fig. 2(e). The saved notes can be shared on Facebook like Fig. 2(f). Another special function is shuffle mode. When you click the button at the bottom of Fig. 2(a), you can enter the shuffle mode. In the shuffle mode, whenever you shake your mobile device, you can see a random card. This function can be used in brainstorming.

2.3. Zone of Contradiction Matrix

A contradiction matrix provides a systematic access to the most frequently used inventive principles to resolve a specific type of a technical contradiction. Fig. 3 shows how to use the contradiction matrix in this application. When a user enters this zone, the main page appears like Fig. 3(a). In the contradiction matrix, the specific type of a contradiction is selected by the pre-defined typical engineering parameters as shown in Fig. 3(b). When the both parameters are selected, the search result from the matrix is shown like Fig. 3(c). The results are linked with the idea cards of the 40 Inventive Principles. Therefore user can check all the cards selected by the matrix as shown in Fig. 3(d).

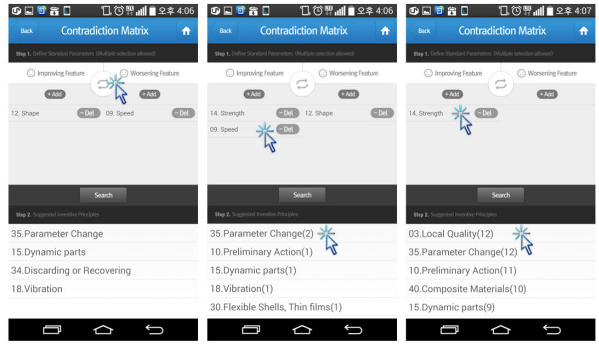
If a user want to select other parameters, he can just go back to the previous menu and follow the same process. All this automatic process enables the user to escape from the inconvenience of manual searching using a complex table.



a) Main page b) Parameter list

c) Search result d) Card list view

Fig. 3. Zone of Contradiction Matrix



a) Switching parameters b) Selection of multiple parameters c) Selection of only one side

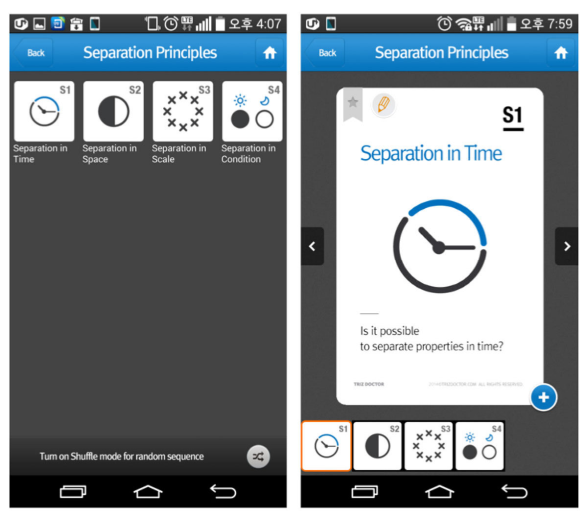
Fig. 4. Selection of parameters

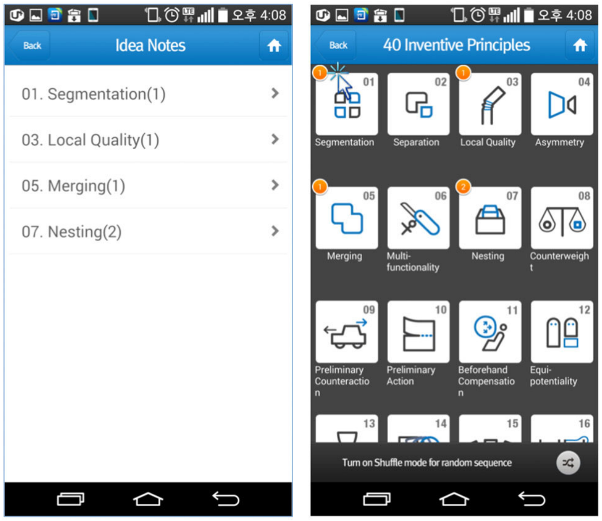
Fig. 4 shows the flexibility of selecting engineering parameters in this application. When we're dealing with a technical contradiction, it is recommended to consider selecting the model that indicates the main function of the system between two technical contradictions. If the selected model is not solved, it is guided to select another technical contradiction [10]. In this application, it is very easy to switch engineering parameters. When the button is clicked, parameters are switched automatically and new results are shown like Fig. 4(a).

When we use the contradiction matrix, it is not easy to select just one parameter from 39 parameters. Selecting multiple parameters is possible in this application. If multiple parameters are selected, all combinations of parameters are searched and the result is arranged automatically as shown in Fig. 4(b). The number in parenthesis means the frequency of inventive principles. Even in the case of selecting just one parameter like in Fig. 4(c), the application can check all cells and arranges the result. Using flexible selection of parameters, the user can freely search all the options.

2.4. Zone of Separation Principles

Fig. 5 shows the zone of Separation Principles. This zone acts same with the zone of the 40 inventive principles.





a) Idea Notes b) Indication of idea notes' number

Fig. 5. Zone of Separation Principles

Fig. 6. Zone of Idea Notes

2.5. Zone of Idea Notes

In this zone, all the idea notes which are generated from 40 Inventive Principles and Separation Principles are arranged together like Fig. 6(a). A user can easily check all the ideas in this zone. In the front page of 40 Inventive Principles menu, number of idea notes is indicated at the edge of each icon like Fig. 6(b).

3. Advantages of TRIZ DOCTOR

- Ease of use: A user interface of the application is very simple and intuitive. A user can very easily learn and practice TRIZ tools. It helps to build familiarity and confidence with the basic tools of TRIZ.
- Interaction: Learners can interact with instructors and students using the same interface. Also, sharing function enables collaboration even in distributed environment. There is no restriction of time and space.
- Portability: It is so bulky to carry textbooks or papers. This application can be equipped in the small mobile device such as smartphones or tablets that we're always carrying. Portability may ensure more frequent use of tools.
- Enhancement of learning: Learning with a mobile application can enhance both individual and collaborative learning experiences. It is very important advantage especially for the beginners.
- Extendibility: Proposed application can be extended to support various functions that are needed for learning and practicing. Also, it can be easily integrated with database system and support various collaborations like online brainstorming.

4. Conclusion

This paper introduces a mobile application named as TRIZ DOCTOR. The application includes TRIZ basic tools such as 40 inventive principles, separation principles and contradiction matrix. It enables trainees to learn TRIZ interactively and to use TRIZ tools even after the class anywhere anytime. Learning with this application can enhance both individual and collaborative learning experiences. As an extension of this application, we're now developing an idea meeting solution. Even in distributed environment, anyone can submit a problem to this solution and suggest many ideas to solve the problem. It is illustrated that our application can be utilized as a good instrument for learning TRIZ.

Acknowledgements

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2A2CI, an effective innovation methodology that makes TRIZ people & business compatible

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Abstract

TRIZ-based innovation methodologies are often very effective when they are deployed by experimented people. But they suffer from at least two drawbacks : firstly, people without expertise in TRIZ show relative reluctance and stay remote from the process; secondly, the results of these methods are quite often not connected with business reality. We propose, with our 2A2CI methodology a TRIZ based tool that facilitates also the adhesion of people even inexperienced with creativity methods and whose results are integrated in a valid business frame which creates growth and value.

Keywords: TRIZ-based methodology ; people adhesion ; business prone; market orientation ; SME-compliant; effective ; pragmatic ; systematic ; innovation

1. Introduction

During ETRIA 2011 [1], we have presented a first framework of our 2A2CI Method (for Awareness – Analysis – Concepts – Concretization – Impact). This structured and systematic approach has been sketched on the base of the IDM-TRIZ (Inventive Design Method – TRIZ) model of INSA Strasbourg, developed during the training of the authors in the Advanced Master in Innovative Design of INSA Strasbourg and improved on several business cases within SME. After 3 years of operational deployment, we have integrated in this method several tools regarding people- and business-orientation, that were lacking in the first version. In this paper, we present this new development of 2A2CI.

1.1. Overview of this article

- At a first stage, we will describe why it is needed to structure innovative design and how it is done with our methodology 2A2CI. We will also describe which improvement we need to implement to make our process more efficient.

- We will then describe how to improve individual creativity in the team, using serious gaming in the process

- In a third part, we will discuss about how to better bring better innovation to the market thanks use of business model canvas.

- To conclude, we will present some forecasting of our methodology.

2. Introduction

2.1. What is 2A2CI ?

2A2CI methodology was designed by xFIVE. The core tool of this methodology is TRIZ. As a support to the work of conception, we use the software STEPS [2], useful to manage a huge number of problems and to document the subsequent concepts of solutions.

2A2CI has been designed particularly for a use in SME. One of its purposes is to implement Systematic Innovation Process in these companies. The final goal is to create sustainable value.

This methodology permits to implement a systematic innovation process within a company. 2A2CI has been drafted in a "hands-on" mode combined with the backbone of the IDM-TRIZ modular chain. It has been constructed on real cases, it has proven being effective in producing results.

2A2CI is mainly based on TRIZ mechanisms, but other tools like Value Innovation or QFD and CEM-KANO have been incorporated in it.

The process is described in Fig. 1.

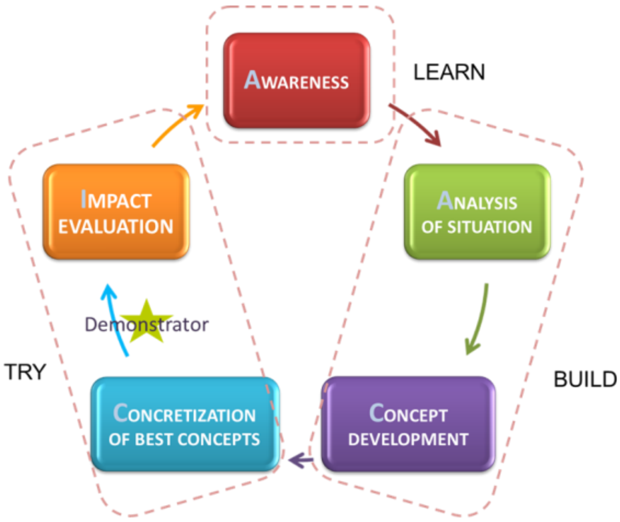

Fig. 1. 2A2CI Process.

Globally, one could divide a 2A2CI intervention in 5 steps:

- Awareness phase (A): making the customer aware that his current situation is full of explicit or tacit problems, developing with him a vision of what he wants to achieve as ideal situation, then convincing him that there exist methodologies to solve these problems and framing the ecosystem wherein his business evolves (customers, clients of clients till end-user, competitors, suppliers, etc.).

- Analysis of the situation (A): exploring all sides and aspects of the problematic, highlighting most critical problems to solve, developing selected key problems into contradictions, and framing the specifications of solutions.

- Developing Concepts of solution (C): using all TRIZ (or non TRIZ) tools to collect concepts of solutions. At the end of this stage, we have a database of concepts of solutions.

- Concretization (C): transforming concepts of solution into refined concepts that can be embodied in a demonstrator and tested experimentally; protecting them through IP policy, etc.

- Impact on (super-) system (I): measuring the impact of the solution on the super-system, e.g. testing the demonstrator in the market with pilot customer during "customized test missions", and using this information to refine all prior steps.

With this process, we obtain, as deliverable, a demonstrator which is tested on the market. With this demonstrator, the customer can decide on the potential of the value proposition for further GO/NO GO on the project.

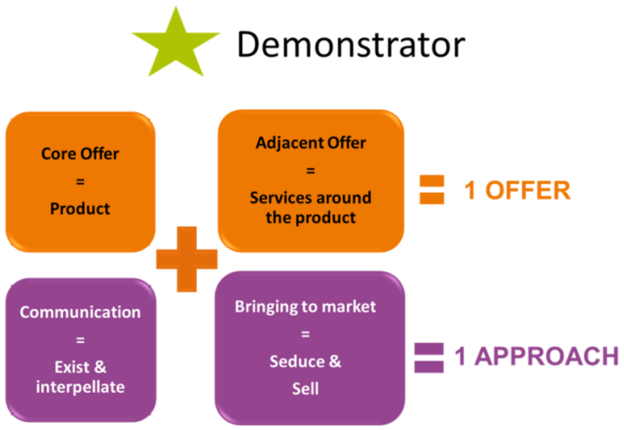

Fig. 2. Demonstrator

2.2. Why to improve 2A2CI?

Application of 2A2CI methodology in SME has delivered good results:

- New products (as MOBI33, an e-Health mobile application for nurses,…).
- New value proposition (as ADER, a new way of selling services for plant protection and nutrition,…).
- Etc…

At the occasion of these successes, we have noticed two major facts (one internal and one external to any innovation methodology) that are necessary to be embodied in the process:

First fact, internal to any process: RELUCTANCY TO METHODOLOGIES.

People are reluctant on the long term to methodologies, especially if there is any link to creativity, because they feel that creative thinking and acting in a frame are contradictory terms. People do like find their own way even if methodologies provide effective paths to diminish energy.

Second fact, external to any process: THE MARKET DECIDES.

Innovation is not decided by the people making innovation, but by the market buying innovation. No adoption by the market means no innovation, at best invention. Even if there is great novelty, it needs to be adopted by customers (in large sense), because it answers a market frustration.

3. Fighting reluctance and improving individual creativity & team efficiency

Hereafter some facts about situation in organizations:

- People do not like methodologies.
- People are resistant to change.
- Synergic team working is on the long run more effective than lonely efforts.
- Creativity is an individual, personal activity.
- Creativity is an essential ingredient of the inventive act.
- In organizations, there are many trainings oriented on work efficiency, and very few on directed creativity

Our proposal is to integrate some activities into the first steps of 2A2CI, activities based on serious gaming, so that it lowers the barriers to creative thinking.

Our philosophy is *"Tell me, I'll forget. Show me, I'll remember. Involve me, I'll understand"* – ***B. Franklin***

For this purpose, we use a set of TRIZ- based games [3] developed by Séverine Baudrux (a Belgian Teacher in elementary school) and Yves Guillou (R&D manager with TRIZ expertise).

These games have been initially used in classroom. Then, together with Axel Neveux and Xavier Lepot (xFIVE founders with TRIZ expertise), they have been applied in different business cases with very good results.

3.1. Description of these games

The entire set is composed with eight TRIZ-based card games. They are listed hereunder:

- Contradiction
- Specialization / Generalization
- Unification (sport)
- Multi-screens
- Division
- Smart Little People
- Imaginary animals
- Similarities and differences

Fig. 3. The TRIZ-based games

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The games help to prepare next steps of the process, putting people in an open attitude.

3.2. Example 1: similarities and differences

For example, in this game, one must find, for 3 objects, what is similar and what is different to a model card.

The "similarities and differences" game helps people to identify the parameters of an object. It permits to find some similarities between situations as well as differences. It helps to point out which parameter can be adjusted to comply to the ideal solution.

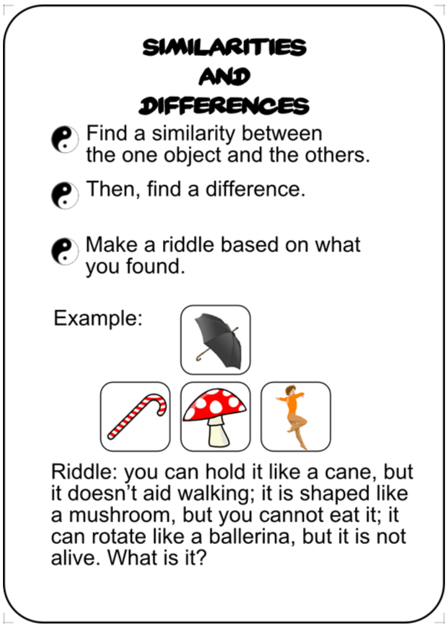

Fig. 4. Example of similarities and differences

3.3. Example 2: the division game

The "Division" game helps people to identify each important parameter of an object. It is also a good starting point to think about new functions that could be satisfied by using parts of an object. The process is to decompose the object into its constitutive parts. Notice that it is not taking into pieces an object, but identify each part by its function.

Fig. 5. Example of division card

4. Integrating market dynamic in value proposition

Here again, some known facts about innovation:

- Market decides.
- There is a cultural bias (especially in the western way of making business): one doesn't like to think about problems as opportunities for new perspectives but as handicaps that need to be fixed as quickly as possible.
- Ecosystems are seen mainly as "Ego"-systems, which means that we look at external stakeholders as we believe they are, not as they are really acting.
- The foundation of a SME is mainly based on a product that answers a certain market need. Thus the SMEs are prone to remain product-oriented (more than market-oriented).

Our philosophy in working at market orientation is to ask to the people concerned what are their problems, not what are their solutions. *"If I had asked people what they wanted, they would have said faster horses." –* ***Henry Ford***.

Our proposal is to integrate Business Model Canvas (BMC) [4] into the 3d & 4th step of 2A2CI. Thanks to support of BMC, the demonstrator of the value proposition can be easily developed in 4 components:

- The **product** itself (wherein inventive activities are mostly valuable).
- The **service** around the product (wherein it is important to understand what are the real problems of the customer chain).
- How we **communicate** around the value proposition (need to exist & to interpellate).
- How we **commercialize** the value proposition (need to seduce & sell)

This approach has been applied in different business cases with very good results, by **xFIVE** together with **Cohesium** (company specialized in market positioning).

4.1. Introducing business model canvass

Business Model Canvas is a great tool to understand how to create value, deliver value & capture value.

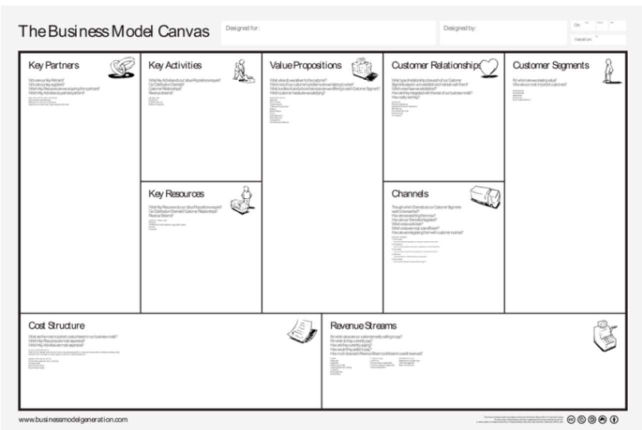

Fig. 6. Business Model Canvas

With the Business Model Canvas, the question *"How to bring my product on the market ?"* becomes "How to bring value added proposal to my customer in the best way ?".

Business Model Canvas helps to select the most promising concepts of solution (those who bring real added value in the marketplace).

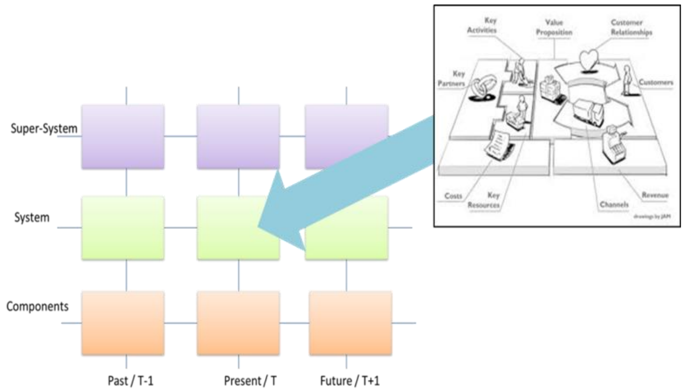

Fig. 7. Coupling Multi Screen Scheme and Business Model Canvas

Combining Business Model Canvas (BMC) with multi-screen scheme brings new vision for the company and allows to define more precisely the strategy in accordance with the particularities of the company and its environment.

Thanks to BMC, one can define what is the core product to be developed. BMC emphasizes also the importance of service that goes with the product.

By knowing also what defines the quality of the customer relationship as well as the way we make revenue streaming.

Based on BMC model, it is easier to define how to communicate & how to commercialize product & service around the product.

5. Conclusion

We have noticed a real improvement in creativity & group synergy for teams using TRIZ-based games. The use of BMC as a structure-giving frame for building demonstrators is really effective. A closer link between multiscreen analysis and BMC helps to position the new value proposition and to upgrade it by using the evolution laws**.**

2A2CI is a methodology in constant evolution, in the search of "ideality" as any process. At each step, one could upgrade the efficiency of the tools that are used. For instance, it would be worthwhile to develop tools that are increasing "collective intelligence" in the teams.

2A2CI stops with the testing of a demonstrator. But customers are finally looking for the deployment of a new value proposition. So, it is important to add to 2A2CI a step of **Industrialization**. 2A2CI would become 2A2C**2**I.

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Improving the value of products and processes by combining value analysis techniques and lean methods with TRIZ

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Abstract

Value Analysis aims to improve the "value" of products, processes and services by examining the relative cost and importance of customer perceived functions. Lean methods focus on finding and eliminating waste. TRIZ enables the functions of technical systems to be defined, modelled and improved. This paper describes how these approaches can contribute to value optimisation and examines ways to combine them into a systematic value optimisation method to improve the value of products and processes. This paper builds on previous work done by the TRIZ community to apply TRIZ to Value Analysis while also providing a Lean perspective on manufacturing processes. Although a generic example has been used to demonstrate the approach, this method has been successfully applied to a number of real world engineering systems and manufacturing processes.

Keywords: Value Analysis; Value Engineering; Lean; Functions; Process Analysis

1. Introduction

The concepts behind Value Analysis were originally developed by Laurence D Miles when he was employed as a Purchasing Engineer at GE in the early 1940s. In this role, he worked with GE suppliers to reduce cost and material usage on many electronic parts and assemblies. At this time, because of the war, there were shortages of skilled labour, raw materials, and component parts. His methods, which emphasised function instead of product hardware, were a big step forward compared with earlier part based cost reduction approaches. According to Miles, functions should be defined using two words, a verb and a noun, for example "contain water" for a drinking cup. In his process, the value of a product is determined by analysing its functions and then comparing their relative importance to the customer (functional worth) with their cost (functional cost). Good value functions show high functional worth at low cost; poor value functions are usually of low worth but high cost. By the time Miles published his first book [1], he had further refined his classification of functions into "basic" and "secondary" categories, which gave some objective guidance to assess functional worth. Early on, Miles realised that poor value often occurred when the root problem was not addressed. This in turn was mainly due to a lack of methods to expose the real problem and a lack of will or knowledge to solve it [2].

At the same time as Miles was refining his Value Analysis method, Genrich Altshuller and his team were working on TRIZ in Russia. Like Miles, Altshuller focused on function and value, for example developing the breakthrough concept of the ideal system [3] which provides a vision of an optimal value solution. Over the following years, the TRIZ community continued to evolve new ways to map and rank functionality [4] and even developed methods to model the underlying physics of a system [5]. As it stands today, TRIZ contains tools to expose root problems and methods to connect with the knowledge needed to solve them, answering the two issues Miles highlighted. In addition to this, the traditional Value Analysis process has already been significantly enhanced by using TRIZ based function analysis [6].

Lean is a management philosophy based on the Toyota Production System, which emerged in the 1980s but was only identified formally as "Lean" in the 1990s [7, 8]. As with TRIZ and Value Analysis, Lean has a strong focus on value as defined by the ultimate customer. Value is created by the producer; from the point of view of the customer, this is the only reason producers exist. Sadly for the producer, value is often very hard to define. Another key concept in Lean is muda, the Japanese word for waste (or non-value-added work). Muda is defined as any human activity which absorbs resources but creates no value. Taiichi Ohno (1912-1990), a key exponent of the Toyota Production System, identified seven types of waste: Transport, Inventory, Motion, Waiting, Over-production, Over-processing and Defects [9]. Over the years, lean has grown to include other methods such as the Theory of Constraints. The Theory of Constraints is used to find the most important limiting factor (i.e. constraint) that stands in the way of achieving a goal and then systematically improving that constraint until it is no longer the limiting factor. In manufacturing, a constraint is often referred to as a bottleneck.

2. The Value Analysis method

Today, a number of different variations on the original method proposed by Laurence Miles are used to analyse the value of products and processes. Value Analysis is now often viewed as a team-based rather than individual activity. The Value Analysis team follows a number of steps, answering different questions at each stage:

2.1. Scoping

Key question: What part of the product or process is going to be analysed and improved? During this step, the team identifies the key interfaces of the system being studied and agrees the boundaries of the analysis.

2.2. Information gathering

Key question: What information will be required to support the analysis? In most Value Analysis projects, essential information includes good quality, current cost data for the product with costs for sub-components, material and all process steps. It is often useful for the team to gather other information such as specifications, customer feedback and even competitor samples.

2.3. Functional description

Key question: What functions does the product or process perform? Functions are identified and mapped, often in a hierarchical form (i.e. as a function tree).

2.4. Function/Design relationship

Key question: How do the functions relate to the existing design solution? The team lists the "hardware" (e.g. components, process operations and equipment) used in the current design and identifies which "hardware" items support which functions.

2.5. Functional cost analysis

Key question: How much does it cost to deliver each of the functions? The costs for each "hardware" item is allocated across all relevant functions using the links found in step 2.4.

2.6. Functional worth analysis

Key question: How important are each of the functions to the customer? The team agrees a relative ranking for all the functions of the product and/or process.

2.7. Value optimisation analysis

Key question: Is the cost being put in the right places? Functional cost and functional worth are mapped together and the team identifies functions which are good value and functions which are poor value. The team generates concept options and agrees a shortlist of preferred solutions.

2.8. Implementation

Key question: How will the value improvements be delivered? The team agrees an action plan with resources to deliver the solutions identified in step 2.7.

In the next section the first seven steps will be used to provide a template for a case study in which traditional Value Analysis thinking is merged with TRIZ and Lean concepts. This example will be used to demonstrate an improved approach to product and, more specifically, process Value Analysis.

3. Case study – hand torch body

Although this case study uses a generic example instead of a real industry product and process, all the concepts and methods shown have been successfully applied on client projects and have proved to be robust. The product example is a hand torch (flashlight) made by Maglite in the USA. The specific product being studied in this case study is the Mini Maglite AA Xenon – see upper panel of Fig. 1. As will become clear, the scope of the case study has been adjusted and narrowed to enable a clearer view of the tools and approach to be provided. In real world Value Analysis projects, a broader or even iterative scoping is more normal.

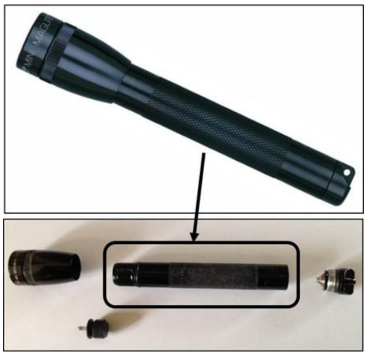

Fig.1. Mini Maglite AA Xenon hand torch and body.

In the following sections we will introduce the improved Value Analysis method by following the first seven steps listed in section 2.

4. Setting the study scope

This Value Analysis will study one part - the body of the torch (shown in the lower panel of Figure 1). This is a machined and anodised aluminium part. The interfaces of this part are identified and the boundary of the analysis further tightened to concentrate on the body machining process. The existing machining system used to make the body is fully depreciated and this study will help define the best option for future capital investment. The design of the torch body and nearby parts can be changed if this results in improved design for manufacture and product value. The torch body is currently produced in an automatic (CNC) lathe in which the raw aluminium tube stock undergoes a number of machining operations to create the final torch body form. The anodised finish on the part is produced in a later process which is outside the scope of this analysis. Fig. 2 shows the interfaces for the torch body (i.e. the components the body "touches") and the overall process to make the part. The dotted lines highlight the area of interest.

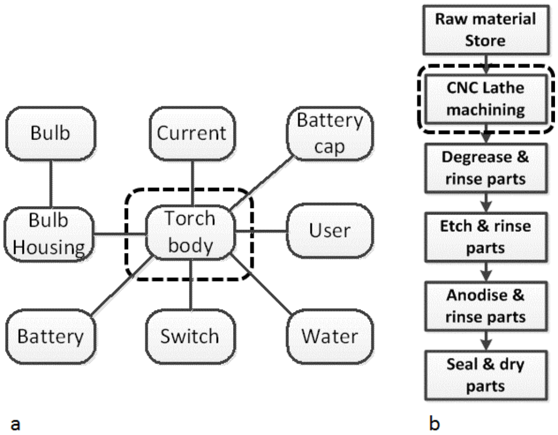

Fig. 2. (a) Interface diagram for torch body; (b) CNC machining in overall torch body manufacturing process.

The CNC machining process consists of eleven operations from loading of tube stock to removal of the completed part. We will include all eleven operations in this analysis. In order to identify the key components which directly interact with the part during the process, an interface analysis is carried out. The process operations are mapped and all the components which directly touch the part are identified for each stage. Fig. 3 shows a process interface diagram which follows the part through the CNC machining process and identifies the components which the part touches during its manufacture. Note that the "target" of the process (i.e. the part) changes at it is transformed from raw material to final form. The focus area for this study is shown by a dotted boundary line.

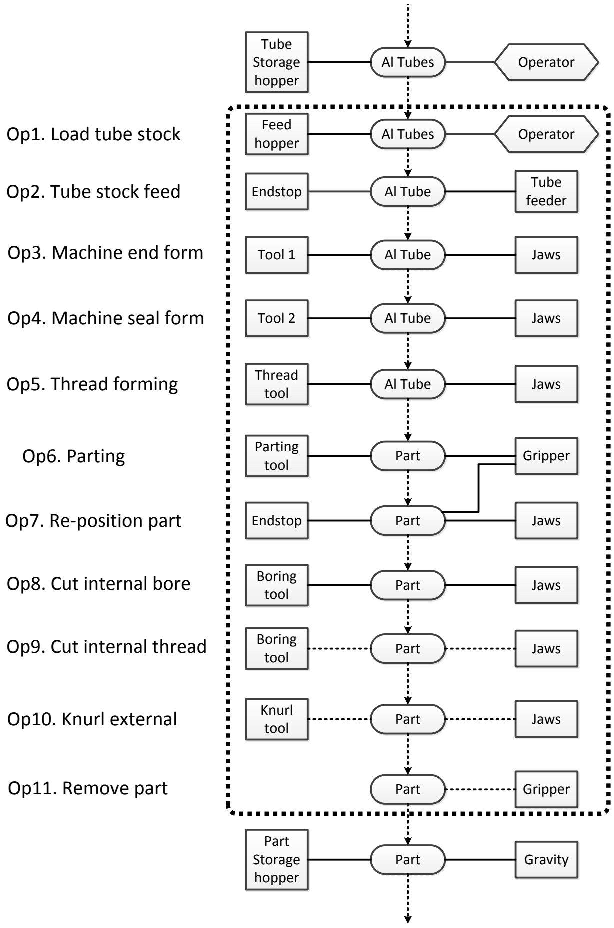

Fig. 3. Process Interface Diagram and scope boundary line for the torch body CNC machining process.

4. Information gathering for Value Analysis

A critical element of any Value Analysis is the quality of the information used. Cost data should be trustworthy and up-to-date and process information should be comprehensive. Consistent rules should be used to deal with issues such as the way capital cost is accounted. In the case of the torch body, a detailed study of the costs for each processing operation has just been done, taking into account all the contributory factors including consumable parts, service costs, inventory, machine time, and operator rates. Fig. 4 shows the cost summary for each of the CNC lathe operation steps.

Operation	Cost/1000 items ($)
1. Load tube stock	1.50
2. Tube stock feed	2.00
3. Machine end form	20.00
4. Machine seal form	8.00
5. Thread forming	20.00
6. Parting off	7.50
7. Reposition part	2.00
8. Cut internal bore	30.00
9. Cut internal thread	19.00
10. Knurl external	16.00
11. Remove part	1.50

Fig. 4. Cost data for torch body CNC machining operations.

5. Functional description

Traditionally in Value Analysis the functional description concentrates on what the product or process does rather than its specific design. Any mention of "hardware" is discouraged and each function is structured in verb + noun format. TRIZ function mapping is a little different - both the actions between components and the components themselves are shown. To illustrate this, Figure 5 shows a partial function tree for the torch which was created according to function analysis rules [10] and Figure 6 shows a more detailed TRIZ (physical) function map. The two arrows in Fig. 5 denote the two navigation questions that are asked when preparing a function tree - why? To move higher in the tree; how? To go into more detail (down the tree).

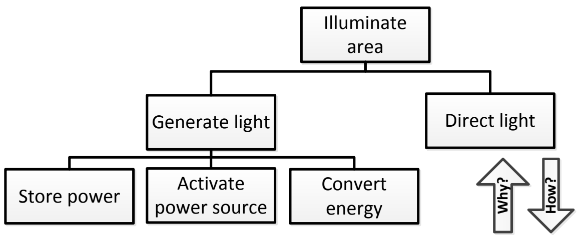

Fig. 5. Partial function tree for hand torch.

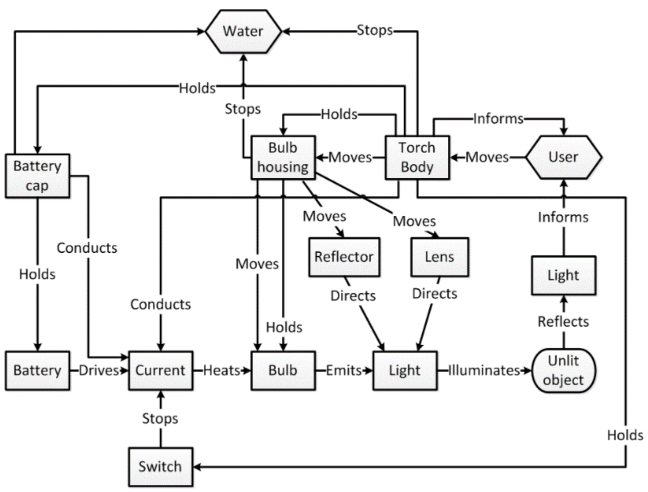

Fig. 6. TRIZ function map for hand torch.

Both tools have a role to play when understanding functionality. The function tree shows the hierarchy of the system functions and provides a way for the team to identify functions which do not relate closely to the operation of the system – e.g. legal requirements and certain "non-use" aesthetic functions. The function map gives a view of the relationship of the current components of the system to each other, the physical actions between them and the different types of action present – e.g. useful, harmful, insufficient or excessive. This diagram only shows useful actions.

Processes can also be described hierarchically and physically, in a similar way to products. A process function tree differs from that of a product in the following ways:

- Any process is made up of a number of operations or steps
- Each operation can comprise a number of functions

Fig. 7 shows a partial function tree for the torch body CNC machining process. The operations are listed in sequence from left to right.

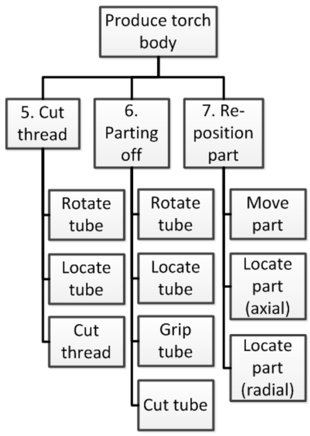

Fig. 7. Partial function tree for hand torch body machining process.

As in the case of the process interface diagram, the "target" of the process undergoes changes as it passes through the process operations. This means that the TRIZ physical function model of a process often looks somewhat different from that of a product. Fig. 8 shows a partial map of the physical actions in the CNC process. As with the product analysis, this diagram only shows useful actions.

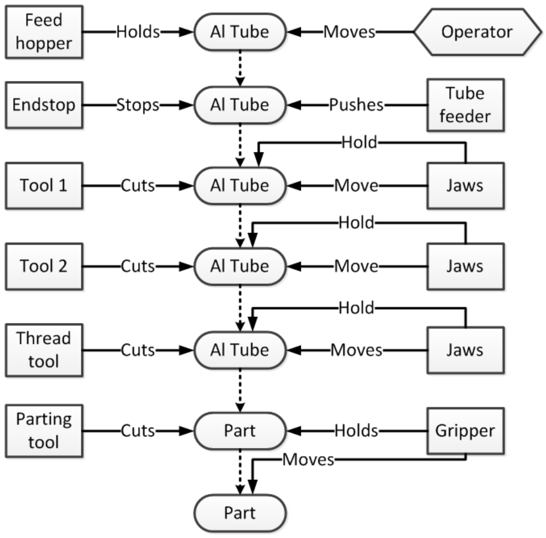

Fig. 8. Partial physical function map of body machining process.

	1. Load tube stock	2. Tube stock feed	3. Machine end form	4. Machine seal form	5. Thread forming	6. Parting off	7. Reposition part	8. Cut internal bore	9. Cut internal thread	10. Knurl external	11. Remove part
Op Cost	1.5	2	20	8	20	7.5	2	30	19	16	1.5
Function											
Inform user					x					x	
Move light source			x		x			x		x	
Hold light source			x		x			x			
Control current			x		x						
Conduct current			x		x			x	x		
stop water				x		x			x		
Hold power source						x		x	x		

Fig. 9. Matrix linking part functions to process operations.

6. Relating the function to the design

Costs for products are not usually assigned against product functions. Product-Design relationship mapping enables product functions to be linked to the elements of the design which normally carry the cost – i.e. the "hardware" of the product design and process. Connecting "hardware" costs to the functions enables the value analysis team to decide how costs are allocated to functions.

In this case study, the scope has been focused on the CNC machining process to make the torch body form. The design and "hardware" costs relate to the process rather than the part materials. In a "real world" Value Analysis project the material and part cost are usually included as well. The torch body functions can be derived from the TRIZ function map – see Fig. 6. From this diagram, the torch body is involved in the following functions:

- Inform user
- Move light source
- Hold light source
- Control current
- Conduct current
- Stop water
- Hold power source

Note that all the function descriptions above have been generalized in line with usual Value Analysis practice. Fig. 9 shows a matrix linking the torch body functions to the process operations. The team have marked the boxes where process operations create features in the torch body which directly impact product function.

It may seem strange that some of the columns in the matrix have been left empty – why has this been done? To answer this question we should recall that, in Lean, the only reason a process exists is to create value for the customer. In order to provide value, a process step must either make changes which are detectable in the end product or directly enable these detectable changes to be made. For example, an injection mold tool directly creates a part form, but is enabled by cooling of the part in the tool. By this definition, other operations or functions which simply move or hold the part between steps do not contribute value. These operations are instead classed in Lean terms as muda – in this case, transport, waiting and inventory. We will discuss these concepts further when we review process function classification.

7. Functional cost analysis

Once the product-design relationship mapping has been completed and each part's contribution to function has been determined, the next step is to allocate costs to each function. In functional cost analysis, the team allocates costs against each function. For each part or process step, the cost is spread over the product functions it relates to. The proportions allocated are an estimate of how much of that parts cost contributes to that product function. When the evaluation has been completed for each part, the function costs are summed. The output of the functional cost analysis is an estimate of how much, in total, it costs to provide each function in the current design.

Because the team was unable to link the muda operations to any functions, they have the option of either creating an additional "not allocated" row and record the costs there or, as in this example, leaving the costs unallocated. Fig. 10 shows the matrix with the costs apportioned between the functions. The total costs for each of the functions is summed on the right hand side of the matrix.

	1. Load tube stock	2. Tube stock feed	3. Machine end form	4. Machine seal form	5. Thread forming	6. Parting off	7. Reposition part	8. Cut internal bore	9. Cut internal thread	10. Knurl external	11. Remove part	
Op Cost	1.5	2	20	8	20	7.5	2	30	19	16	1.5	
Function												**Cost**
Inform user					2					8		10.00
Move light source			4		2			1		8		15.00
Hold light source			12		8			10				30.00
Control current			2		4							6.00
Conduct current			2		4			1	9			16.00
stop water				8		4			5			17.00
Hold power source						3.5		18	5			26.50

Fig. 10. Matrix sharing operation costs between part functions.

This matrix format provides a very neat way of tracing the decisions made by the team, helping the team to defend their decisions against future challenge.

8. Functional worth analysis

Once the costs have been allocated, the team can start to look at the value of the product and process functions. In this section, we will review two ways to explore the relative importance of functions – one focused on product functions, the other on the process. Also we show how concepts from TRIZ and Lean are both used to guide the Value Analysis team. We will start by discussing how to classify and value product functions.

8.1. Product functional classification

Product functional classification is an objective way of assessing the relative importance of different product functions. Each function is reviewed and classified. The function classifications are used to help the team assign a ranking to the functions. Product functional classification can be used to assist in finding the functional worth of each product function. The table in Fig. 11 provides a guide to classifying functions.

Type of Funct.	Purpose	Example Tool	Action+Object	Priority
Primary	Justifies existence of system	Hammer head	Move nail	Maximum
Enabling	Supports the performance of the primary function	Hammer handle	Move hammer head	Medium to high
Enhancing	Boosts the primary function	Arms on sun lounger	Support the users arms	Medium to high
Additional	Extra functions performed by the system	Advertisement on cup	Communicate information	Medium
Measure / detect	To gauge or detect the parameters of a system's components	Control strip on a battery	Measure the battery voltage	Low
Corrective	To eliminate or alleviate undesirable effects in the system	Thermal insulation in a thermos flask	Stop heat transfer	Very low

Fig. 11. Listing of product function types in descending value order.

In the case study, the team used these function types to categorise the functions of the hand torch body as shown in Fig. 12. The team used an additional guideline – the lower the function in the tree, the less important the function.

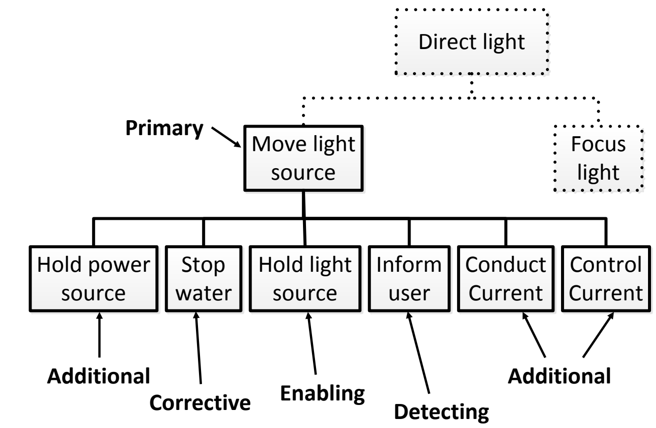

Fig. 12: Torch body function types.

When these classified functions are compared using a tool such as pairwise comparison [11] a ranking can be produced for the relative importance of each function. Figure 13 shows the ranking developed by the team.

	Rank
Informs user	2
Move light source	9
Hold light source	8
Control current	6
Conduct current	4
Stop water	1
Hold power source	5

Fig. 13: Function ranking for torch body.

In TRIZ there are other well-known ways to compare the worth of product functions, for example, function ranking [12]. This approach can also be helpful when assigning functional worth for Value Analysis. Another important input to consider during product functional worth analysis ranking is customer feedback. This can take many forms beside customer questionnaires. Depending on the product, customer complaints, warranty issues, direct consumer behaviour observation, visit reports, specialist press publications and forum discussions can yield valuable insights.

8.2. Process functional classification

Process functional classification provides an objective way of assessing the relative importance of different product operations. Each operation is reviewed and classified. The classifications are used to assign a ranking to the operations. Process functional classification can be used to assist in finding the functional worth of each operation. The table in Fig. 14 shows the different types of process operation, their relative value and relates each to possible forms of muda. The Lean perspective on this ranking sharpens the prioritisation process by drawing our attention to the medium to low value operations and challenging us to find ways to eliminate them.

Type of Operation	Purpose	Example	Priority	*Muda* category
Primary	Brings about changes which are detectable in the final product	Forming a molded part in a tool	Max.	N/A
Enabling	Changes the object's parameters to enable a primary operation (not detectable in final product)	Cooling a molded part	Medium to high	N/A
Transport (including orientation)	Changes the object's position in space without directly enabling a primary operation	Moving a part between assembly stages	Medium to low	Transport, Motion
Storage	Maintains the object's position in space without directly enabling a primary operation	Holding parts in batches between assembly stages	Low	Inventory, Waiting
Measure / Detect	To gauge or detect the parameters of a system's components	Detecting or inspecting a part	Low	Over-processing, Waiting
Correcting	To eliminate or alleviate undesirable effects in the process	Pre-heating a part to improve adhesion	Very low	Defects, Over-processing

Fig. 14: Listing of process operation types in descending value order.

Using the outputs from the process function tree and physical function map, the team listed the CNC machining operations and sub-operations to make the torch body. They then assigned a score to each. The team used a 0-5 scoring system with Primary operations scoring 5 and Corrective operations scoring 0. Fig. 15 shows an excerpt from the full process rating. The score for each operation (op-score) was calculated from the average of the sub-op scores for that operation. The team also identified muda sub-operations.

Op	Sub-op	Type	Op Score	Sub-op score	Muda
1. Load tube stock			1.50		
	Operator loads tubes	Transport		2	T, M
	Hopper positions tubes	Storage		1	I, W
2. Tube stock feed			2.00		
	Tube feeder transfers tube	Transport		2	T
	End stop locates tube	Transport		2	T
3. Machine end form			4.00		
	Jaws rotate tube	Enabling		3	
	Jaws locate tube	Enabling		3	
	Machine outside diameter	**Primary**		5	
	Machine tube end	**Primary**		5	

Fig. 15: excerpt from operation and sub-operation scoring.

In traditional Value Analysis, the team makes a judgment about the relative importance of the process functions based purely on their knowledge of the process. Product and process functional classification improves on this by providing the team with some objective guidance to decide their rankings. However, do the process rankings fully reflect product functional worth? The Lean concept of value is helpful, but it gives little guidance on the relative worth of Primary operations (of which there are often several). What is needed is a way to connect product functional worth to process operations. Fig. 16 shows a matrix which does just this. In this matrix, an overall operation score is calculated by multiplying the operation score by the weighting (rank) for each product function it supports. The total is summed for each operation to derive a deployed importance score. This score is converted into a percentage value to make later analysis easier.

		1. Load tube stock	2. Tube stock feed	3. Machine end form	4. Machine seal form	5. Thread forming	6. Parting off	7. Reposition part	8. Cut internal bore	9. Cut internal thread	10. Knurl external	11. Remove part	
		1.5	2	4	3.67	3.67	3	1.5	3.67	3.67	3.67	1.5	**Op Score**
		1.5	2	20	8	20	7.5	2	30	19	16	1.5	**Op cost**
Function	**Rank**												**Costs**
Informs user	2					7.34					7.34		10
Move light source	9			36		33			33		33		15
Hold light source	8			32		29.4			29.4				30
Control current	6			24		22							6
Conduct current	4			16		14.7			14.7	14.7			16
Stops water	1				3.67		3			3.67			17
Holds power source	5						15		18.4	18.4			26.5
Deployed importance		0	0	108	3.67	106	18	0	95.4	36.7	40.4	0	
% Deployed importance		0%	0%	26%	1%	26%	4%	0%	23%	9%	10%	0%	

Fig. 16: reflecting product functional ranking in process operational importance.

This form of analysis rewards process operations which contribute to a number of product functions and penalises those that only support one or two. Note that process operations 1, 2, 7 and 11 have received a zero score. This result is in line with their classification as muda operations. The outputs from this matrix enable the team to focus on the relative worth of the Primary and Enabling operations in the next stage of the analysis.

9. Value optimisation analysis

The goal of Value Analysis is to find and improve the product and process functions which are poor value, while maintaining or enhancing functions which provide good value. By comparing functional worth against functional cost, high value and low value functions and operations can be clearly identified. Once we know the low value operations in a process, we can focus on finding solutions which address the root causes of poor value. In the previous sections, we have already discussed some very low (or zero) value muda operations. In this section we will discover how to highlight the lower value primary and enabling operations and find root-causes. We will then outline some possible value improvement solutions.

9.1. Comparing functional worth and cost

As a result of the work done in the last steps, the team now has costs for both product and process functions. Because of the scope of this study, the team plan to concentrate on finding poor value operations in the CNC machining process. There are a number of ways to visualise functional worth and cost. Traditionally, a bar graph showing functional worth and cost each function or operation is prepared. Fig. 17 shows a graph prepared by the team to compare functional worth and cost for the torch body machining process. This graph lists the operations in descending deployed importance with costs for each.

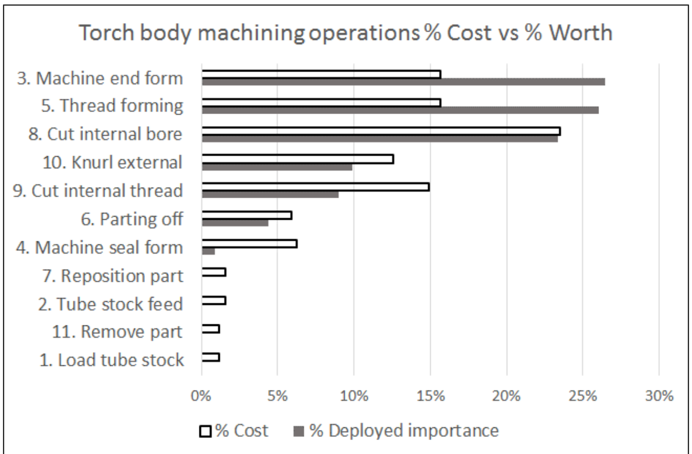

Fig. 17: Graph showing process worth (deployed importance) compared with cost per thousand items for each operation.

Two operations emerge from this analysis as possible candidates for value improvement:

- Machine seal form – an operation which has a low importance but relatively high cost
- Cut internal thread – an operation which has a relatively higher importance but a possibly disproportionate cost profile.

In order to get a clearer view of the value of each operation, the team decide to calculate the value ratio for each operation. This is a relative measure of value and is derived by dividing the deployed importance by the cost per thousand for each operation. Fig. 18 shows the value ratio graph for the CNC machining operations. The dotted line shows the average value ratio calculated for all value-added operations (i.e. not including zero value-added muda operations). Any operation which falls below the line has less than average value.

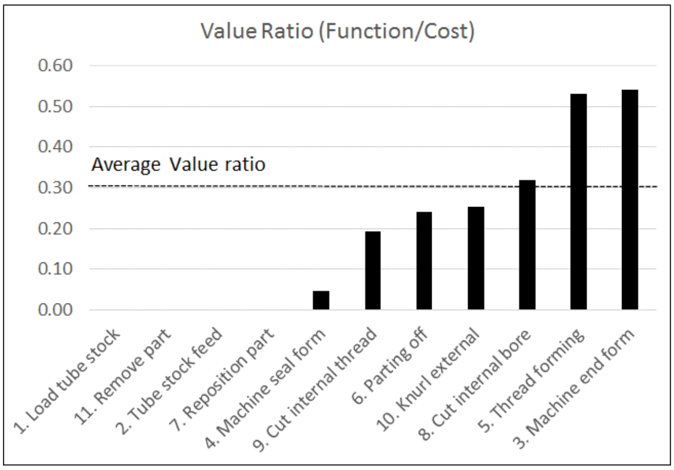

Fig. 18: Graph of value ratio for CNC machining process operations.

This analysis reveals that not only are the operations machine seal form and cut internal thread relatively poor value but that parting off and knurl external are also possible value improvement candidates. The team decide to focus their studies first on the two lower value operations. In the next section we will describe how the team get to the root causes of poor value in these operations.

9.2. Cause-Effect Analysis

One of the reasons problems can be hard to solve is that they are often expressed in broad and superficial ways. In Value Analysis, the output of the function worth and cost comparison can sometimes lead to problems which are expressed at too high a level. Many years ago, Miles recognized this issue when he highlighted the lack of methods to expose the real causes of poor value. Cause-effect analysis provides a way to investigate an initial problem and uncover the underlying causes (root problems). In the last few years the TRIZ world has adapted cause-effect analysis and integrated it into the early steps of TRIZ problem analysis. Cause-effect analysis can be very helpful when used to investigate value problems. We will now review this approach applied to our case study.

In the case of the hand torch body machining process, the team set out to explore two problems:

- The operation machine seal form is poor value
- The operation cut internal thread is poor value

The results of their cause-effect analysis on the first problem is shown in Fig. 19.

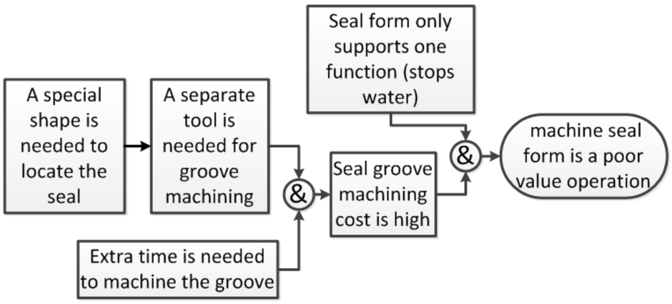

Fig. 19: Cause-effect diagram for machine seal form is a poor value operation

The team started at the right of the diagram with the initial problem. By asking "Why?" or "What is the cause of this?" the team uncovered deeper reasons for the problem. If two or more causes all have to be present for the initial problem to occur, the team connect the causes to the problem with & (logical "AND"). If the presence of either one of the causes is enough to lead to the problem the team use OR. At the end of the analysis, the team identify three root causes of the problem which each suggests a different solution direction:

- Root cause 1: Seal form only supports one function (stops water) – solution direction 1: change design so the seal form is used for multiple functions
- Root cause 2: Extra time is needed to machine the groove – solution direction 2: change the machining process so that groove is cut at the same time as other operations
- Root cause 3: A special shape is needed to locate the seal – solution direction 3: Use the same shape as that formed by another process operation

Later we will discuss potential value improvement options which follow one or more of these solution directions. Next we will review how the team addressed the poor value of the operation cut internal thread. Fig. 20 shows the cause-effect diagram for this problem, with the initial problem again placed on the right of the diagram and root causes near the left.

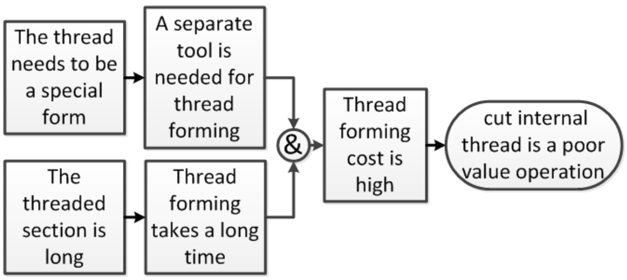

Fig. 20. Cause-effect diagram for cut internal thread is a poor value operation

This time the team traced the initial problem back to two root problems:

- Root cause 1: the thread needs to be a special form to retain the battery cap - solution direction 1: use the same shape as that formed by another operation
- Root cause 2: the threaded section is long - solution direction 2: Find a way to shorten the threaded section

Next we will consider options to enhance both product and process value by addressing the problems identified in this section.

9.3. Value improvement

Before addressing the problems identified in the cause-effect analysis, the team decided to look at potential solutions to take out or minimise the zero value-add muda operations discussed earlier. The four operations were:

- Operation 1: Load tube stock
- Operation 2: Tube stock feed
- Operation 7: Reposition part
- Operation 11: Remove part

In Lean there are two types of muda – one which is unavoidable given current technologies and assets and one which can be avoided. The first is called Type One muda and the second is Type Two muda. The scope of this project allows big changes to the CNC machining centre and part design, but some allowance will still be needed for loading of material and removal of parts – i.e. as some element of these operations contain Type One muda it will be difficult to remove them completely.

9.4. Improving the value of muda operations

Operation 1: Load tube stock. The tube stock is already cut to length by the supplier before shipping to the factory. The team propose the tube is cut to into final lengths and delivered direct to a gravity feeder on the CNC machine rather than into the stores.

Operation 2: Tube stock feed. The team decide to combine this operation with operation 1 and use gravity feed and small auto-loader (which is sometimes fitted as standard on modern CNC lathes).

Operation 7: Reposition part. The need to re-orientate the part can be avoided by using a dual turning system which machines both ends of the part at the same time. This will also reduce overall cycle time significantly.

Operation 11: Remove part. Type One muda – no change.

9.5. Improving the value of lower value operations

Operation 4: machine seal form.

Starting with the three root causes from the cause-effect analysis, and particularly focusing on solution direction 3, we find we have a conflict:

- In order to hold the seal the seal form must be a special shape
- In order to avoid having a separate tool and operation, the form must not be a special shape

The problem now becomes – how to hold the seal without a special form? See Fig. 21. The best way to address this problem is to apply trimming [13]. This means the solution should take one of these three routes: the seal holds itself somehow, some other nearby "resource" holds the seal or we get rid of the seal altogether but still stop the water.

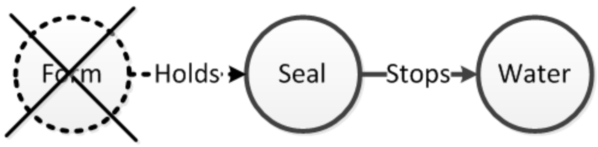

Fig. 21. How to hold the seal without a special seal form?

It is perhaps a little hard to see how the seal could hold itself – maybe it could be bonded to the tube in some way, but there are plenty of resources close by which could also help to hold the seal. For example, we already have a thread on the hand torch body and an end form to the body. There are also local parts such as the bulb support molding and lens housing. In the machining process, we find the nearby actions of thread cutting and turning. One solution which emerges from this is to change the design of the bulb support molding and torch body end to sandwich the seal in place, taking away the need for a separate seal form. Going one step further, the seal could be removed altogether by using hydrophobic coatings on the body and lens housing.

Operation 9: cut internal thread.

The cause-effect analysis revealed a very similar conflict to that for the seal form:

- In order to hold the battery cap (and battery) the thread form must be a special shape
- In order to avoid having a separate tool and operation, the thread form must not be a special shape

These conflicts lead to virtually the same problem and solution strategy as the earlier example – see Fig. 22.

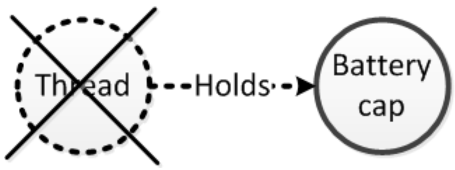

Fig. 22. How to hold the battery cap without a thread?

The battery cap itself offers a potential resource to provide the holding action. Exploring this direction leads to an interesting concept in which the battery cap is an interference fit within the torch body. The threaded section at the other end of the body is used to provide battery access with the bulb unit combined into the lens housing. Fig. 23 shows a schematic view of this concept. This (admittedly quite radical) design change would remove the need for a separate threading operation and could also take away much of the costly inner bore machining operation.

Fig. 23. Alternative torch construction concept.

10. Conclusions

As well as enhancing the standard Value Analysis approach the methods shown in this paper have been proven to work in practice. The case study details new ways to assess the true worth and value of process operations. Taken together, the three approaches of Value Analysis, TRIZ and Lean provide a complementary framework for value optimisation of products and processes. The approach presented here will continue to be the subject of development through project application. One key area for future work is the modelling and Value Analysis of products as processes. This is of particular interest when reviewing products in which the "target" of the product functions changes through the operation of the product.

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A Simple Computer Tool for Applying Usage of Contradiction Matrixes

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Abstract

At TRIZ conferences in 2013 the authors had several discussions with TRIZ users that something like an easy, simple software tool that works with different Contradiction Matrixes and in different languages "would be a great thing to have". The tool should provide an easy access to the parameters and provide an explanation and examples for the suggested Principles.

The team interpreted this as a "customer requirement". So a solution was looked for. The result is an Excel tool, where different Contradiction Matrixes (original Altshuller, Matrix 2010, Matrix for IT and Software) can be loaded together with explanation of the Principles and examples for application from the fields of mechanics, electro technics, IT, life sciences, etc. Selected Contradictions and explanations and examples can be saved easily into a spread sheet for further evaluation.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: Contradiction Matrix, Software Tool for TRIZ, Explanation and Examples for Contradiction Resolutions, TRIZ

1. Today's Situation

There are a couple of very interesting books, where Contradiction Martixes (CMs) are presented differentiating in the field of application [1]. Altshullers original matrix has been born out of the mechanical / electrical area, although the systematic can as well be applied to other non-technical field when translated correspondingly. In the years of evaluation expanded Matrixes have been generated incorporation supplementary parameters (e.g. [2] Matrix 2010 by Darrell Mann with 50 parameters), or by looking into new technology applications like software / IT or even business models [1]. The operation is always the same: define a contradiction with an improving parameter and a worsening parameter and apply the generic Principles suggested to your specific problem to solve it. This last step of back transformation from generic to specific is the hardest part in the process and requires most creativity.

The Matrixes today available are mostly given as table together with an explaining book. The two parameters have to be selected. The corresponding Principles can be found in the cross-section of the row and column and then the ename of the Principle like "Segmentation", "Rush through", Nested Dolls", etc. (Fig. 1) are identified. In the books explanations of the Principles are given and as well application examples. But still for the process of creativity, the back and forth with operating the table, identifying the Principles, understanding what they mean and searching in the books for examples on how they are applied is cutting the creative process into bits and pieces and is thus disrupting creativity.

In literature the Principles have slightly different names which can create further confusion (result of current evaluation done in Germany in a standardization effort, not yet published).

Most books on the TRIZ topic are written in Russian or English language. For somebody who has a different native language a lot of energy can flow into understanding the foreign language which kills creativity again. Creativity works best in your mother language; this has been proven by science (GE internal evaluation).

There are software tools on the market that include CMs and which offer direct access to explanations and examples. E.g. "IHS Goldfire" combines CMs with text and pictures / graphs. But the tools often offer huge supplementary functionalities that are not required but have to be paid for. Such tools regularly are in the 4 digit $ range and require annual maintenance fees. For somebody or a company entering TRIZ application this might be a barrier.Usually first one wants to "get a feeling" and learn about a method before heavily investing.

2. Requirements

Based on this evaluation and Voice of Customers (VoC) which have been conducted by interviewing TRIZ users, the following high level requirements have been defined:

- Self-explaining tool, requiring no additional documentation.
- Different Contradiction Matrixes can be loaded and used.
- It shall be able to add CMs without changing the tool.
- The tool shall provide short explanations and multiple application examples.
- It shall be possible to save selected parameters, explanations and examples into a separate spread sheet.
- Explanations and examples shall be provided in different languages

In the discussions on CMs that shall be included the question on copying arose. As the CMs have been compiled into books the authors make money out of book selling. Transferring the CMs into a digital form may lead to digital copying that contradicts the book selling. For that purpose a supplementary requirement, coming from the Principles "pre-action" and "change parameters", was introduced:

- CMs shall be protected from digital copying.

3. Realized Tool

Turning the requirements into a real tool we decided to develop an Excel based tool. The platform Excel is widely known and used. Everybody is familiar with its usage and with VBA (Visual Basic Application) it can be programmed as needed. The tool consists of a core file called "TRIZ_Tool_Contradiction_Matrix_Excel" and a subdirectory called "TRIZ-Wizards" that contains the different CMs. The CM files are structured in 3 spread sheets: Contradiction Matrix (CM) itself, Principles and Explanations/Examples. The CM files all represent a different set of CM, e.g. the original Altshuller Matrix, the expanded Matrix 2010, a CM for IT, a CM for Software and a CM for business application. These CMs are set up independently from the evaluation tool itself and stored in separate files. By this copyrights can be considered.

The core file consists of three spread sheets as well:

- "Setup" for language selection and explanations (Fig. 2)
- "Contradiction Resolution" where CM can be selected with the "Pick-Wizard" button (top left), the improving and worsening parameters are selected, the adequate Principles are displayed and upon selection of a Principle the corresponding explanation / example are displayed (Fig. 3). Furthermore with the "Save" button the selected Principle and its explanation / examples can be saved in the third spread sheet, the
- "Saved Resolution". Here the results are collected for further analysis (Fig. 4).

The CMs are protected by passwords so that digital access for copying is denied. Reference is given to the used CMs as well as to the sources / books. The translation of the explanations / examples into different languages was done by the national MATIZ organizations in France, Spain, Italy and Germany.

4. Example of Usage

The usage of the tool shall be explained by usage of an example. Assume the parameter to be improved is "length of the moving object" and the parameter not to be worsened is "shape".
The Excel tool is started and on the first table (fig. 2) the preferred language is selected. Then upon activating the second table, in the top left the CM that shall be used is selected. The available parameters for improving (left side) and not worsening (right side) are displayed in the two side by side windows in the middle. With the mouse the two parameters are selected (in this case "length of the moving object" in the left window and "shape" in the right window. In the lower magenta window the corresponding Principles are displayed. On the right side of this window it can be selected if the Principle shall be explained or if technical examples shall be displayed (fig. 3). Depending on the selection under the magenta window the corresponding information is displayed. If this is helpful, the information can be stored in the third table called "Saved Resoultions". In that table all the selected information are presented in a condensed form (fig. 4) so they can further be used for analysis.

5. Summary

A simple but high effective tool on Excel basis is now available for few bugs that can be downloaded from "TRIZ-Campus". This shall help introduction TRIZ further more into industry worldwide.

References

[1] Bukhman, Isak, „TRIZ Technology for Innovation", 2012, Cubic Creativity Company, ISBN 978-986-85635-2-0.

[2] Mann, Darrell, „Matrix 2010, Re-Upodate der TRIZ Widerspruchsmatrix“,Hrsg. Nähler, Horst et. Al., 2013

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	Deteriorate Improve	Weight of moving object 1	Weight of stationary object 2	Length of moving object 3	Length of stationary object 4	Area of moving object 5	Area of stationary object 6	Volume of moving object 7	Volume of stationary object 8	Speed 9	Force (Intensity) 10	Stress or pressure 11	Shape 12
1	Weight of moving object			15 8 29 34		29 17 38 34		29 2 40 28		2 8 15 38	8 10 18 37	10 36 37 40	10 14 35 40
2	Weight of stationary object				10 1 29 35		35 30 13 2		5 35 14 2		8 10 19 35	13 29 10 18	13 10 29 14
3	Length of moving object	8 15 29 34				15 17 4		7 17 4 35		13 14 8	17 10 4	1 8 35	1 8 10 29
4	Length of stationary object		35 28 40 29				17 7 10 40		35 8 2 14		28 10	1 14 35	13 14 15 7
5	Area of moving object	2 17 29 4		14 15 18 4				7 14 17 4		29 30 4 34	19 30 35 2	10 15 36 28	5 34 29 4
6	Area of stationary object		30 2 14 18		26 27 9 39						1 18 35 36	10 15 36 37	
7	Volume of moving object	2 26 29 40		1 7 4 35		1 7 4 17				29 4 38 34	15 35 36 37	6 35 36 37	1 15 29 4
8	Volume of stationary object		35 10 19 14	19 4	35 8 2 14						2 18 37	24 35	7 2 35
9	Speed	2 28 13 38		13 14 8		29 30 34		7 29 34			13 28 15 19	6 18 38 40	35 15 18 34
10	Force (Intensity)	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12		18 21 11	10 35 40 34
11	Stress or pressure	10 36 37 40	13 29 10 18	35 10 36	35 1 14 16	10 15 36 28	10 15 36 37	6 35 10	35 24	6 35 36	36 35 21		35 4 15 10
12	Shape	8 10 29 40	15 10 26 3	29 34 5 4	13 14 10 7	5 34 4 10		14 4 15 22	7 2 35	35 15 34 18	35 1 37 40	34 15 10 14	

Fig. 1: Part of the Contradiction Matrix (CM)

TRIZ INNOVATION TOOL (10. Jan.2014)

Dr. Genrich S. Altshuller, the Russian creator of TRIZ, realized that the most difficult problems in engineering involve fundamental contradictions (trade-offs): A desired improvement of one system parameter causes another parameter to degrade. Thus the system does not perform at least one of its functions perfectly. He realized, however, that often breakthrough solution can be found that satisfy both otherwise conflicting requirements. Altshuller selected the world's most significant inventions and analyzed ways of solving and eliminating the fundamental contradictions. He discovered that just several hundred "**Inventive Principles**" can be used to create solutions for many thousands of breakthrough inventions. Today's TRIZ is based on analysis of approximately 1.5 million inventions worldwide.

Starting from Altshuller's mechanical/electrical dominated contradictions, followers have refined the original matrix and transferred his method to other fields of application like business and IT / software. This Wizard shall help to use different published contradiction matrices in an easy way and for different languages.

Usage:
1) Select your preferred **language** on the "Setup" sheet.
2) Load a contradiction matrix by clicking the "**Pick Wizard**" button on the top left of the "Contradiction Resolution" sheet; then select one of the installed contradiction matrixes files.
3) Select one of the parameters to improve on the left by clicking onto it.
4) Select one of the trade-off parameters on the right.
The corresponding principles will be displayed in the box below.
5) Click onto a principle to show explanations or examples according to the button selected on the right side.
6) Click the "Save" button" to save the selected contradiction and principle pairs in the "Saved Resolution" sheet for later analysis.

Current selected Contradiction matrix
Current Wizard File => CM_Altshuller Expanded Matrix 2010.xlsx
Current Wizard File Description => ©Darrell Mann, Systematic Innovation, systematic-innovation.com, Horst Nähler c4pi
02.Jan. 2014 Version 1.0
02.01.2014

References:
http://en.wikipedia.org/wiki/TRIZ
Isak Bukhman, TRIZ
Darrel Mann, ...
Robert Adunka, ...
Valerie Souchkov, ...

Available Contradiction Matrices (Wizards)
CM_type 1
CM_type 2
CM_type 3
CM_type 4
CM_type 5
CM_type 6

Select preferred Language:
English
(some examples vary from language to language)

Fig. 2: Setup spread sheet of the tool

Pick Wizard

Engineering Contradiction Resolution Wizard

Using TRIZ (Russian Theory of Inventive Problem Solving)

04.01.2014
Version 1.0

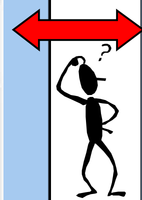
CM_Altshuller Org.xlsx

1 I want to improve . . .

- Weight of moving object
- Weight of stationary object
- Length of moving object
- Length of stationary object
- Area of moving object
- Area of stationary object
- Volume of moving object
- Volume of stationary object
- Speed
- Force (Intensity)
- Stress or pressure
- Shape
- Stability of the object's composition
- Strength

39

Feature to Improve



2 . . . but this causes a problem with:

- Weight of moving object
- Weight of stationary object
- Length of moving object
- Length of stationary object
- Area of moving object
- Area of stationary object
- Volume of moving object
- Volume of stationary object
- Speed
- Force (Intensity)
- Stress or pressure
- Shape
- Stability of the object's composition
- Strength

39

Undesired Result (Degraded Feature)

3 The following TRIZ Principles may help resolve this contradiction. . .

Explain
Example

- 01-Segmentation
- 08-Anti-weight / (weight) compensation
- 10-Preliminary action / do in advance
- 29-Replace solid media by flexible ones (pneumatic / hydraulic) / Charge the degree of freedom

4

Save

	Explanation / Examples
1	MECH: Utility knife blade made with a groove allowing the dull part of the blade to be broken off, restoring sharpness.
2	Problem: Stamps are printed in large sheets but must be neatly separated for use. Principle: Perforations around each stamp make a detachement of an individual stamp easy.
3	Inorder to prevent dusting when blasting a building, water curtains are used.
4	When ramming jackest for off-shore wind mills, air-bubble curtains around the ramming place prevent sound waves to disturb wales, dolphines and fishes.
5	In paper towel dispense the paper is performated for easy tearing.
6	Pre-glue post-its.
7	IT: Dynamic allocation of resources (such as memory) can be time-consuming if performed at the time the resources are needed because the resources must be allocated before they are accessed. A process that requires many allocations can significantly affect performance. Allocate resources
8	Pasteeurized milk.
9	ELEC: Lab-on-a-chip.
10	Pre washed jeans.
11	Ready-to-eat package food.
12	Rubber cement in a bottle is difficult to apply neatly and uniformly. Instead, it is formed into a tape so that the proper amount can be more easily applied.

Fig. 3: Main spread sheet: Contradiction Resolution

Clear All

Saved Engineering Contradiction Resolutions

CM_Altshuller Org.xlsx

Improving Feature	Worsening Feature	Principle	Explanation or Example
Length of moving object	Shape	10-Preliminary action / do in advance	1: MECH: Utility knife blade made with a groove allowing the dull part of the blade to be broken off, restoring sharpness. 2: Problem: Stamps are printed in large sheets but must be neatly separated for use. Principle: Perforations around each stamp make a detachement of an individual stamp easy. 3: Inorder to prevent dusting when blasting a building, water curtains are used. 4: When ramming jackest for off-shore wind mills, air-bubble curtains around the ramming place prevent sound waves to disturb wales, dolphines and fishes. 5: In paper towel dispense the paper is performated for easy tearing. 6: Pre-glue post-its. 7: IT: Dynamic allocation of resources (such as memory) can be time-consuming if performed at the time the resources are needed because the resources must be allocated before they are accessed. A process that requires many allocations can significantly affect performance. Allocate resources before they are needed. 8: Pasteeurized milk. 9: ELEC: Lab-on-a-chip. 10: Pre washed jeans. 11: Ready-to-eat package food. 12: Rubber cement in a bottle is difficult to apply neatly and uniformly. Instead, it is formed into a tape so that the proper amount can be more easily applied.
Length of moving object	Shape	29-Replace solid media by flexible ones (pneu	1: To increase the draft of an industrial chimney, a spiral pipe with nozzles was installe When air flows through the nozzles, it creates an air-like wall, reducing drag. 2: Use an airbag in cars for protection versus a security belt. 3: IT: A process may require a lot of physical memory, more than is available in RAM. Use a paging mechanism in which a linear (virtual) memory address is located in any part of physical memory, including RAM or the hard drive. The part of data not currently used by a process is unloaded from RAM to the hard drive and the part that is needed (page) is loaded from the hard disk to RAM. 4: Problem: Complicated mechanisms are required to control the movement of a manipulator along a complex path. Principle: Usa an arm formed by independant, inflatable compartements. 5: For shipping fragile products, air bubble envelopes or foam-like materials are use.

Fig. 4: Spread sheet Saved Resolutions

Available online at www.etria.eu/portal

TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

Application of Creative techniques in Effective Management of a Power Generation Plant

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Abstract

Creative techniques are methods that can be used to promote novel products and ingenious actions. There is a wide range of creative techniques available for idea generation, employing divergent and convergent thinking for problem definition, exploration of problematic features, generation of solution options, evaluation and implementation of ideas. Essential to their efficient operation is to make use of a suitable creative technique for a particular application and individual or team, to aid in the process of problem-solving, the refinement of old ideas, and the generation and implementation of new ideas. The creative technique described in this paper is TRIZ which is the Russian acronym for Teoriya Resheniya Izobretatelskikh Zadatch meaning Theory of Inventive Problem Solving. This is used for systematic invention. This paper emphasizes the processes and specific TRIZ tools used in the implementation of TRIZ in the effective management of a Power Generation Plant that uses gas turbine engines for its operations. The TRIZ process will be employed for the day to day administration of the activities within the power generation plant. The ideas generated through divergent thinking would be categorised thus providing the required solution of value to the problem in a short time.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: Generation; Plant; Creative techniques; TRIZ, Inventive principles; Ideal Final Result.

1. Introduction

Creative techniques are schemes used to produce creative ideas for solving problems. Creative ideas can be used in the effective management of an Establishment such as a power generation plant. This will include all the phases starting from the conception of the power plant in the development phase to implementation and finally operation of the plants. Creative techniques are usually employed to assist management of an establishment to produce the needed creative suggestions with increased value of the ideas in short periods of time and early on during the problem solving or implementation phase of the policies. This would help valuable ideas from the divergent and convergent thinking session to be implemented early in a developmental phase of the project.

The power generation plant reported in this paper uses a gas turbine engine for its operations. With the increased in the demand for natural gas for electricity generation, it is required that the plant be sited near the source of the supply of its raw material (natural gas). The electric power generation plant consists essentially of at least one land gas turbine engine, transformers, transmission networks and distribution networks. The dependability of electric power system depends on the state-of-the-art information of the system condition for operation and control.

The power generation plant reported in this paper is known as Ibom Power Plant (IPP). Before now, the supply of electricity had been performed mainly by the Power Holding Company of Nigeria, PHCN, whose supply has been grossly insufficient and unpredictable in all parts of the State. Due to this unreliable supplied, private and government businesses have been depending on private generating sets to generate power for their individual depending on their demand. People also generate their own power for domestic purposes with the high costs of fuel and the attendant risks of pollutions

associated with fumes, vibration and noise.
The irregular power supply in the State which has remained a major problem has forced many small scale business operators like dry cleaners, barbers, welders, hairdressers, vulcanizes, beer parlour owners (pubs), supermarkets, hotels, inns and other small scale businesses out of jobs. The government recognizing the influence of electricity in the infrastructural, social and economic development of the State established the Ibom Power Plant to alleviate the suffering of its people and improves the industrial sector of the State in particular and Nigeria in general.

This power generation plant is located in acres of land located in Ikot Abasi Local Government Area in Akwa Ibom State, Nigeria. The power plant is a venture envisaged and owned by the Akwa Ibom State Government through the investment arm the of the State government known as Akwa Ibom Investment and Industrial Promotion Council, AKIIPOC to provide an uninterrupted power supply in the State, with a remaining to be fed into the national grid.

According to Ibom Power plant project website, the Ibom Power plant project which started in 2001 is planned in two phases and has satisfied the requirements of the Federal Government of Nigeria, the Federal Ministries of Energy, Power and Steel, and the Power Holding Company of Nigeria, PHCN. The power plant has two (2) General Electric (GE) frame 6 and one (1) frame 9 gas turbine engines, contributing a total capacity of 180 MW. A132/11KV transformer is installed and a 45km – 132 KV double circuit power evacuation line is then constructed from Ikot Abasi to Eket sub station. 60MW of power of the 180MW is to be dedicated to meet Akwa Ibom's energy needs. The daily energy need of the State was estimated at 30MW were no high volume of Industrial activities, yet the State was receiving between 5MW and 7MW at inconsistent intervals and many communities and industries were not linked to the National grid. However, with the completion of the plant, many communities and industries are now enjoying regular power supply. It is expected that the Ibom Power Plant will provide several thousand of direct and indirect employment opportunities in the State and will offer attractive commercial returns to the State. Figure 1 shows the Ibom Power Plant with the transformers, transmission and distribution networks of the plant.

This massive project requires the application of relevant creative technique by management and indeed staff of the facility for a successful planning and implementation of policies during the construction phase and the operation of the power generation plants. The generation plant is divided into both technical and non-technical departments. The departments are Personnel, Operations, Engineering, transmission network, distribution network and monitoring system department.

With the intention of dealing with the colossal mission associated with the plant management, idea generation and implementation using creative techniques such as 40 inventive principles, the ideal Final result, divergent and convergent thinking would be engaged to circumvent seeming variance during decision making and implementation exercise in the day to day administration of the power plant. This paper reports the application of creativity tools in the in the general administration of the facility noting the massive technical knowledge required in the successful implementation of policies in an electric power generation plant. 40 inventive principles have been customised for use in the general administration of both the technical and non-technical department in the electric power generation plant.

Nomenclature

IPP	Ibom Power Plant
KV	Kilo volt
LNG	Liquefied natural gas
MW	Megawatt
PHCN	Power Holding Company of Nigeria
PV	Photovoltaic (PV)
TRIZ	Teoriya Resheniya Izobretatelskikh Zadatch

2. Background of previous work on creative techniques and power generation plant

Creativity involves all action from the generation of new ideas of value and refining of old ones to the implementation of these lofty ideas to give solution to problems. According to [2], creativity is essential to categorize opportunities and solve problems in a rapidly changing environment. Creativity is usually measured based on its characteristics which are ability, attitude and a process. For details on creativity, the reader is referred to work according to [2-8]. Several types of creative technique have been developed for problem solving in both technical and non-technical areas and the development and application of the range of these creative techniques are reported by [9-15]. The creative technique use in this study is called Theory of Inventive Problem-solving (TRIZ). This incorporates other techniques and concepts such as inventive principles, the ideal final result, resources, divergent and convergent thinking employed for the rapid solution generation for problems solving.

Power generation plant has continued to serve as centres for reliable energy generation and service for both private and commercial power consumption on a daily basis. To smooth the process of power supply for both private and industrial activities, power plants encountered many problems in the everyday operations of the plant. Decision-making problems which are a major factor must constantly be solved to make efficient the operations such as generation and transmission of power, thereby giving the consumers steady and efficient supply of power. For this reason the need for relevant creative technique to help in solving these constant occurrences. The services provided in a power generation plant are generation and transmission of power. A brief mention of previous work relating to power generation plant is presented here. Some of the studies are:

- Key Factors Affecting the Deployment of Electricity Generation Technologies in Energy Technology Scenarios
- Natural Gas Power generation in the presence of wind

- A Life Cycle Comparison of Coal and Natural Gas for Electricity Generation and the Production of Transportation Fuels
- The Coal-powered Electricity Market in China
- Analysis of Thermal Power Stations and their Interaction with the Power System
- Natural Gas Power generation in the presence of wind
- Nuclear Power Plants and Sustainability
- Power generation
- Network and capacity distributions
- Power plant security
- Personal and personnel management
- Ownership of plant and alliances
- Plant operations
- Safety management

For details on these studies, the reader is referred the works by [16-22].

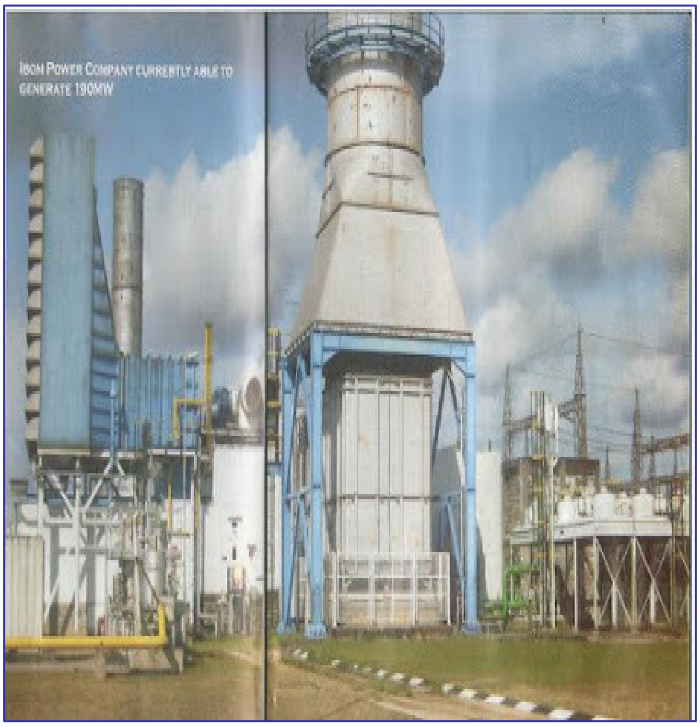

Fig.1.**The Ibom Power Plant shows the transformers, transmission and distribution networks of the plant courtesy of Ibom Power plant project website.**

3. Implementation of the Creative technique

TRIZ is the Russian acronym for Teoriya Resheniya Izobretatelskikh Zadatch meaning the 'Theory of Inventive Problem-solving.' It is the creative technique employed in this study. This incorporates the 40 inventive principles. The 40 inventive principles process will categorise the problem and then present possible solutions to solving the problem by generating new ideas or refining old ideas. It will facilitate the narrowing down of the generated ideas during brainstorming and divergent thinking session and then analytically decide on the most promising ideas for further consideration [1].

3.1. Application of 40 inventive principles in the management of a power generation plant

40 inventive principles are the total set of generic solutions that populate the contradiction matrix [23]. They are frequently utilised to narrow the field of potential solutions to a given technical contradiction [24]. This technique is applied along with the helpfulness of ideal final result, contradiction resolution, divergent and convergent thinking to accomplish the purposes of establishing the power generation plant. This technique will give a resourceful set of possible solutions to problem facing the management of the power generation plant at any moment in time within a given limitations. For detail on inventive principles the reader is referred to the work by [25-29]. The 40 inventive principles for the management of a power generation plant are given in Table 1.

Table 1: 40 Inventive Principles for the management of a power generation plant

SN	Principles	Examples
1	Segmentation	• Create major department for example infrastructure, engineering, security, operations, information technology, personnel, Account. • Create a sub group or teams out of major department for example generation, network and distribution units from the operation department.
2	Taking out	• Outsourcing some duties for example distribution of power and collection tariff. Others are safety issues, security, restaurants and bars. • Eliminate all extraneous work including overtime works for safety reason. • Make accurate replacement to non-functional part in engine, transformers and machines in the power section facility for efficient power generation. For example the removal of combustion products from gas turbine engines, the removal of heat resistant coatings on blades, vanes and liners in gas turbine engines.
3	Local quality	• Develop management strategies to suite the location and cultural need of the site of the power plant. • Continuous in-house

		training of personnel in the management of the plant. • The use of flexible elements capable of withstanding high temperature and pressure fluctuations for gas turbine expansion joints, which are intended to withstand thermal movements and vibration without imposing any loads on the connected components.
4	Asymmetry	• Change management approach to recruitment to enhance productivity. • Change from conventional ways of service delivery to customised way to enhance performance for example the use of digital pay as go meters.
5	Merging	• Merging sub-units with similar service delivery for a better service delivery. • Encouraging partnership between different power plants.
6	Universality	• Organization of the activities of the power plant to meet international standards. For example, using universally accepted computer tomography and fingerprint devices for security monitoring. • The use of digital transformers that can be adjusted to varying power requirements for distribution.
7	Nested doll	• Create organisational chain within each department for an effective working environment. For example from the generation of power to networking to distribution of power to meter reading and collection of tariff. • The management should ensure the use of a turbine blade damper-seal assembly. This is a seal nested within a damper, such that both the seal and damper is disposed to provide sealing between adjacent blade platforms for efficient performance of the gas turbine.
8	Anti-weight	• Assign a supervisor to a unit of workers for proper guidance. • Outsource some projects like monitoring power line, security, restaurants and bars. • Management should bring in power generation expert from the academia from time to time in different areas for professional advice for better performance. • The management should opt for gas turbine with titanium-based alloys for compressor blades, fan blades, discs and hubs for high strength and low weight of the gas turbines.
9	Preliminary anti-action	• Conduct regular checks of both mechanical and electrical equipment before power is generated and distributed to ensure safety and compliance with local and international laws and regulations. • Engage in an open active and informative communication through print and electronic media in the plant operations and scheduling to avoid misunderstanding by customers. For example when the power plant is under turn around maintenance. • During the turn around maintenance, abradable material should be used to cover the casing of a high pressure compressor (HPC) to prevent harmful effects (rubbing) of rotor blades on casing during engine operation.
10	Preliminary action	• Provide at the entering gate to the plant with route map and leaflets indicating no go areas to visitors for safety and to ease their movement within the facility. • Maintain sign poster with arrows directing to major danger zone and major department within the plant. • Early information dissemination of changes in the plant operations using print and electronic media is essential to help industrial usage. This will not disrupt their continuous operation. • The use of auxiliary power units (APU) to provide power to start the main engines of a gas turbine engine. • A routine inspection of the

		power generation unit before any start up of the plant is essential.
11	Beforehand cushioning	• Generate in progress communication system in the form of a television (T.V) screen in all departments which allow for continuous update of the activities within the plant and showing update in the major department. For example the current power generation in megawatt and any disruption in the networking and distribution line, etc. • Use metal detector and security guards at the entering gate to the power plant t to screen vehicle and people entering inside the plant to prevent sabotage and other criminal activity within the establishment. • Management should have departmental contingency plan in case of emergency. For example disruption of power and distribution lines by vandals. • Operators and others within the power generation unit should ensure the use of ear muffs.
12	Equi-potentiality	• The use of equipment with different operational needs in the plant operations. For example computer that are used for computer tomography and for storing and accessing information. • To ensure the operation of a gas turbine engine over a design cycle with different operational conditions depending on the required power output.
13	The other way round	• Conduct quarterly evaluation of the plant operations and management performance through questionnaires. This will give independent feedback from customers for action by the management team. • Make rotation of staff within a department a priority to avoid monotonous of work (being bored).
14	Spheroidality-Curvature	• The use of 3D computer device instead of 2D device for accurate crime detection for example in the computer tomography operations. • Make use of of rolling gate with ball bearing as an alternative of swing gate to avert accident in the facility and preserves space. • Use mobile services on wheels such as repair unit and meals on wheels within the plant.
15	Dynamics	• Provide continuous training to staff to meet with the continuous development in the area of information technology, safety and engineering. • Encourage the use of inter telecommunication between departments and personnel for effective service delivery. • Adjust to the dynamic changes in engineering and information technology.
16	Partial or excessive actions	• Recruit and train people on internship in power generation, networking, distribution and meter reading. Student on industrial attachment and graduate on national service should be used to fill vacant position due to retirement and staff absent on leave. • Engage experts on part time employment for effective service delivery. • Continuous communication between management and staff through the departmental head to strengthen staff work security.
17	Another dimension	• Use multi-storey to accommodate office block and car parks to save space within the plant facility. • It is essential to use an axial compressor with several stages, instead of a centrifugal compressor, to increase engine pressure and efficiency.
18	Mechanical vibration	• Causing an object to oscillate or vibrate. • Power plant management should communicate frequently with staff and customer through newsletters, electronic media (T.V, Radio, and Website), telephone, text message and quarterly report to avoid friction. • Coordination of plant scheduling for effective power distribution. • The use of strategic

		planning to get the organisation to the right frequency for a high-quality service delivery. • Ensure the control of stall, or surge development in the axial compressor of gas turbine engines by the measurement of its frequency.
19	Periodic action	• Daily and weekly report instead of quarterly report of departmental operations to the head of department for effective decision making exercise. • Offer periodic training to staff on new development within the department to increase productivity. • Introduction of off-duty days for staff to revive people's mind and increase productivity. • Introduction of sabbaticals to help transform management staff perception of the plant operations.
20	Continuity of useful action	• Retention of expert retiree staff of each department on part time employment. • Continuous use of intercom for effective communication among staff within the department for effective service delivery.
21	Skipping	• Conduct harmful or hazardous operation quickly. For example clear the facility of debris quickly to avoid accident within the plant environment. • Resolve operational conflict within the plant quickly to avoid a drawback.
22	Blessing in disguise	• Management should accept negative feedback from customers as a springboard to bounce back with innovative ideas to improve service delivery.
23	Feedback	• Management should accept feedback from customers as a springboard to bounce back with innovative ideas to improve service delivery or continue with an existing good method.
24	Intermediary	• Hire consultants. For example external auditors, consulting engineers and fire servicemen. • Engage expert in the power plant generation and gas turbine engineers in brainstorming and problem solving sessions for new ideas. • Contract out services like cleaning services. • Management to ensure the use of a thermal lining to insulate the casing from the rotor for a better engine efficiency. • Ensure thermal coating on aerofoil to reduce thermal growth..
25	Self-service	• The use of waste resources to enhance productivity within the facility. For example the use of waste engine oil on rollers and ball bearing in rolling gate for a smooth movement of the gate. • Re-engage retired workers to positions that their experiences are needed.
26	Copying	• Use electronic database instead of paper work. For example personnel personal data and in accounting. • The use of audiotape for training and instructions instead of attending a seminar. • To ensure the use of Virtual monitoring of the workings of gas turbine engines via a computer.
27	Cheap short-living objects	• Use disposable papers and plastic cup in the office to reduce the cost of maintenance. • The use of computer a simulator to reduce cost of training. For example the use of a plant simulator to reduce training cost. • Engage temporally staff for non-critical positions. For example in cleaning services.
28	Mechanics substitution	• The use of electronic information system to monitor and deliver information within the facility from a central point instead of using personnel. • The use of closed-circuit television (CCTV) to monitor the facility to prevent crime. • The application of electrical heating to the casing to modulate tip gap, instead of using mechanical systems such as screw thread devices (actuators) to selectively

		move axial rotor assemblies to alter the clearance for efficient engine performance.
29	Pneumatics and hydraulics	• The use of flexible organisation structure in department with fixed hierarchal structures. • Flexible policies in non technical and security services. • Ensure the use of hydraulics and pneumatic system for lifting of heavy equipment.
30	Flexible shells and thin films	• Use 'Trade secret' methods to separate organisation proprietary knowledge from general knowledge. • Differentiate between plant management policies from general government policies in the generation and distribution of electricity. • To ensure staff works efficiently, flexible hours of work should be employed by the management.
31	Porous materials	• Power Plant management should improve internal communications by creating internet and intranet accessible to all workers. • Management should set up and maintain updated website.
32	Colour changes	• Develop friendly community and business partnership with the local communities to enhance peaceful co-existing. • The power generation plant authority should use strong corporate colours for image branding. • The organisation should have a clear, concise vision and mission statement. • To promote employee diversity.
33	Homogeneity	• Employment of indigene people to exchange cultural knowledge with non-indigene. • The use of common data transfer practices between different departments within the establishment.
34	Discarding and recovering	• Eliminate duplication of duties through accurate scheduling. • Eliminate duplication by supplier through accurate inventory. • Encourage periodic re-

		training of workers.
35	Parameters	• Motivate workers with excellent work award certificate. • Promotion/ elevation of workers to encourage effective performance at work. • The use of flexible working hours. For example encouraging shift work to reduce fatigue at work.
36	Phase transitions	• The application of developmental plan from power generation, networking and distribution.
37	Thermal expansion	• Expand or contract operations facilities depending the need of consumption and number of using the route. • Provide incentives to worker to increase productivity.
38	Strong oxidants	• Boost interaction. For example encourage staff members to attend professional courses and seminars. • Ensure total commitment to vision and mission statements of the power plant company. • Consider the radical re-organisation of the establishment in line the emerging global trend. • To ensure the use of anti-oxidants to inhibit the formation of peroxide compounds in certain gas turbine fuels.
39	Inert atmosphere	• During problem solving sessions, the atmosphere should be free from criticism and judgment to ideas and participants. • Encourage multi-cultural working environment in the power plant facilities. • Encourage the use of third party for conflict resolution between management and trade union in difficult times. • To encourage the use of fuel additives in gas turbine engines to control high temperature corrosion of blades and vanes.
40	Composite materials	• Encourage the use of multiple modes of information dissemination for example through newsletters, intranet,

		website and departmental staff meeting. • Use both high/low risk management and investment strategy. • Use multiple training techniques such as lecture, simulation and online teaching in staff training to equip them well in their complex working environment. • The use of multi-disciplinary project teams in the operations of the power plant. For example in engineering team with civil, electrical, mechanical and computer engineers.

4. Conclusion

TRIZ methodology is used to stimulate ideas and find solutions to problems. The introduction of TRIZ methodology to the management of a power generation plant will assist this management with original and ingenious decision making through divergent and convergent thinking during idea generation and implementation sessions.

The 40 inventive principles will facilitate the categorisation and thinning down of creative ideas by management with the aim of carrying on specific ones for further analysis during brainstorming sessions for implementation. The examples show that TRIZ techniques, such as the inventive principles will support decision making processes in the proper management of Ibom Power Plant and indeed any power generation plant for positive results. TRIZ methodology should be in use in the general administration in a power generation plant.

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TRIZ Future Conference 2014

System Solutions for Increasing Nanofibre Production through TRIZ

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Abstract

An increase in the production of production lines for inorganic nanofibres is a very complicated and complex problem that depends on the intensity of the electrostatic field. This complex system may show, under given input and output conditions, variable and nearly chaotic behaviour that may consequently cause fluctuations in the electric field intensity manifested by reduced efficiency of the process. An increase in the intensity of the electrostatic field may be carried out by known methods, for example by increasing the electric potential, changing of the environmental conductivity between the electrodes through changing the relative humidity or by replacing the air with an inert gas. However, the higher total intensity of the electrostatic field may not lead to an increase in process efficiency or productivity. This is due to the fact that the main parameter is involved especially in the spatial intensity distribution of the electrostatic field. Other important parameters having an impact on the optimum process are the distance and the type of electrodes, the chemical structure and properties of the polymer solution, ambient temperature, intensity of vapour removal and others. Through TRIZ tools the influence of the polymer reservoir geometry on the electrostatic field distribution were studied. The structural geometry of the polymer reservoir carries a rotating electrode. The rotation creates a thin layer of the polymer on the surface of the roller, but it also stirs the solution – Nanospider principle. It was found that the geometric design and the relative permittivity of the used construction materials have a significant effect on the final distribution and the maximum electric field intensity at a given electric potential. The resulting intensity of the electric field can be understood as a system that is described by a complexity. This system includes subsystems in the form of input parameters such as electrical potential, the polymer type, humidity and temperature of the environment, duration of spinning, as well as the structural design of the polymer reservoir geometry.

Keywords: TRIZ, productivity, production line, nanofibres

1. Introduction

Increasing the productivity of machinery and equipment is necessary for efficient and economical production. While some technologies are already approaching the theoretical maximum productivity, some emerging technologies that are still being implemented must be continuously improved and modified. Such technologies include the Nanospider electrospinning method. The principle is based on spinning from a free level [1,2] with non-spinning technologies. The device is arranged so that the roller is positioned in a reservoir of a polymer solution, whereby the rotating roller attracts the polymer solution to its surface. Due to electrostatic forces, nanofibres are removed from polymer, which are then stored on a grounded or oppositely charged electrode. Compared to the spinning from a needle this technology provides significantly higher performance, but it is not comparable with other technologies producing nanofibres [3-6]. The need for the development of this technology is the possibility of preparing nanofibres from certain types of polymers which are not spinnable using other technologies. This technology has a wide range of technology and process parameters which have not yet been fully explored and thus offers the possibility to increase productivity by their appropriate setting. This article deals with innovation and design optimization of the technological parameters of equipment, namely a reservoir for the polymer, to which TRIZ methods are applied.

2. Material and methods

2.1. Solving the problem using TRIZ

The finding and optimization of a suitable solution can often be inefficient, time-consuming and costly. This is because a certain level of inertia is applied leading to the use of proven principles that do not always lead to the optimal solution. One option for achieving a relatively rapid solution is the TRIZ [7], which is used to solve various innovative tasks [8-10]. TRIZ is a method that is applicable to solving technical contradictions that arise in typical solutions. The Altshuller table [11] was used during the research. The TRIZ and its tool the Altshuller table was applied during the group workshop. When applying this table it is necessary to start with parameters we want to improve. Then we should find typical solution which leads to improve of chosen parameters and also find the parameters which will get worse when the typical solution will be used. When analyzing the characteristics of the equipment and the possibility of increasing the productivity, parameters were sought that could bring about the desired improvement in terms of increasing the efficiency and productivity of the equipment. In the first column of the Altshuller table we can find parameters that are close to the requirement of increasing the productivity. Two parameters were identified that best fit this requirement i.e. **39 – Productivity** and **21 – Power**. These parameters have to be improved. **A typical solution** leading to increased productivity of the equipment in the case of electrospinning is **increasing the voltage** as mentioned in [6, 12, 13]. To improve the parameters we searched for parameters that would worsen in a typical situation. They can be found in the first row of the table. Too high voltage levels would lead to an increase in power consumption **20 – Use of energy by a stationary object**. Increasing the voltage to too high a value leads to arcing between electrodes which temporarily disconnects the high voltage circuit. This problem is identified as **31 - Object-generated harmful factors**. A shutdown of the source is connected to **25 - Loss of time** and **27 - Reliability.** Possible solutions can be found at the intersection of improving and worsening parameters. Individual numbers are assigned to the heuristic procedures to overcome technical contradictions. The possible solutions are listed in Table 1, which also indicates the overall incidence of the solutions.

Table 1. Heuristic principles of technical contradictions

Heuristic principles	Frequency [11]
35. Transformation of the physical and chemical states of an object	4
1. Segmentation	2
10. Prior action	2
18. Mechanical vibration	2
24. Mediator	2
37. Thermal expansion	2
2. Extraction	1
6. Universality	1
19. Periodic action	1
20. Continuity of a useful action	1
22. Convert harm into benefit	1
26. Copying	1
38. Use strong oxidizers	1
39. Inert environment	1

The most frequent occurrence is in **principle 35.** This principle includes, among other things, a change in parameters and properties of the object, density, etc. Others include principle **1 - Segmentation**. This has previously been applied in the modification of the roller and creates a large variety of geometrical modifications.

2.2. Proposal of new design through TRIZ

By using TRIZ innovation of the existing structure of the polymer reservoir was designed. From principle 35 it is obvious that this can be done in the following ways. Object parameters may be seen primarily as a change in geometry (shape dimensions, the linear dimensions, bulk parameters), or also a change in the structural material, thereby altering the relative permittivity which affects the resulting distribution and magnitude of the electrostatic field. The geometry of the reservoir was designed in CAD SolidWorks 2012 taking into account the production and use of construction material. The actual structural design of the reservoir was also proposed with regard to the dimensions of the spinning electrode and also the same volume of the polymer solution. The individual designs are presented in Fig.1.

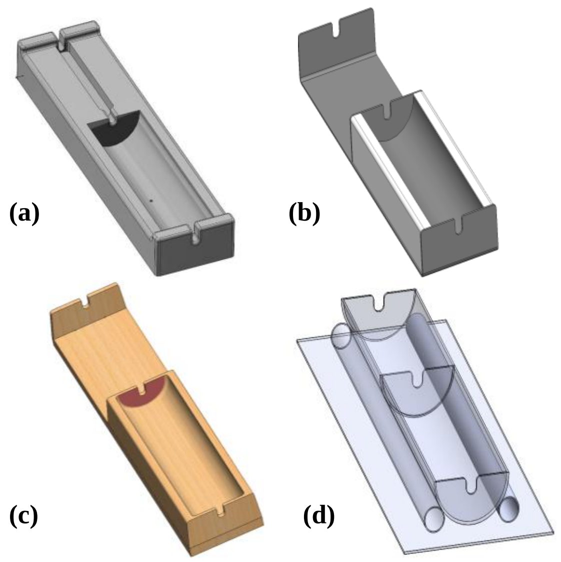

Fig. 1. (a) Reservoir made from PP Beige (current state); (b) Reservoir made from steel; (c) Reservoir made from wood; (d) reservoir made from glass

3. Verification

Verification of designs of the reservoirs was performed first using the finite element method, which facilitates and considerably reduces the cost of prototyping [12-16]. Based on the results from the FEM models, functional prototypes of the reservoirs were made, which were further verified in practice.

3.1. Theory

The potential distribution and the electric field intensity are very difficult and almost impossible to measure during the electrospinning process using the Nanospider. A certain possibility is to create a simulation in the FEM environment. The FEM model contains: the electrode - polymer solution - reservoir - the external environment - closed box, as was described in [1, 4, 12, 13]. The electric field can be approximately defined as limiting force acting on unit charge by the equation (1).

$$\vec{E} = \lim_{q \to 0} \frac{\vec{F}}{q} \qquad (1)$$

where $\vec{E}$ is intensity of electric field, $\vec{F}$ is acting force, q is elementary charge.

The electric $\vec{E}$ field can be determined by the voltage between two positional vectors r1 and r2 defined by the equation (2)

$$U = \int_{r_1}^{r_2} \vec{E} dl = \varphi(r_1) - \varphi(r_2) \qquad (2)$$

where $\varphi(r_i)$ expresses the potential of the electric field. In materials the external environment defines the vector of electric induction $\vec{D}$ described by the eq. (3).

$$\vec{D} = \varepsilon_0 \vec{E} + \vec{P} \qquad (3)$$

where ε_0 is permittivity of vacuum ($\varepsilon_0 = 8{,}854187817 \cdot 10^{-12} F \cdot m^{-1}$), $\vec{P}$ is electrical polarization described by equation (4).

$$\vec{P} = \varepsilon_0 \chi \vec{E} \qquad (4)$$

where χ expresses the electric susceptibility of the material (for air it is $\chi = 0{,}00054$).

The source of the flow of electrical charge is the induction of a more precise electric field. The Gauss theorem of electrostatics is applied (3. Maxwell equation) which describes that the flow (divergence) of electric vector induction through a closed surface which surrounds the charge is proportional to the amount of charge q and does not depend on the shape of the surface S which is described by the Einstein summation convention (5).

$$div\vec{D} = \lim_{\Delta V \to 0} \frac{\int_S \vec{D} d\vec{S}}{\Delta V} \equiv \partial_i D_i \text{ and } \oint_S \vec{D} dS = q \qquad (5)$$

where V the volume of the electric field.

In the electrostatic field the work done by the charge q on close loop is independent on the path. It is described by a closed integral according to equation (6).

$$rot\vec{E} = \left(rot\vec{E}\right)_i = \lim_{\Delta S_i \to 0} \frac{\oint \vec{E} d\vec{l}}{\Delta S_i} = \varepsilon_{ijk} \partial_j E_k = 0 \qquad (6)$$

where ε_{ijk} is Levi – Civita permutation symbol.

From equation (6) and (7) follows that the intensity of the electric field $\vec{E}$ can be seen as potential gradient ϕ describable by the Laplace - Poisson equation as follows in equation (7).

$$grad\phi = -\frac{\rho_{\vec{D}}}{\varepsilon_0} \qquad (7)$$

where ρ_D is the density of electric induction.

3.2. FEM models

Models were created in the FEM program COMSOL Multiphysic. Geometry, properties of individual materials and applied boundary conditions correspond to the real spinning process. The main parameters were the permittivity of the used material (see Table 2) and the applied voltage, which had a value of 60 kV on the spinning electrode, and the opposite electrode was grounded. The parameters are shown in Chart 2.

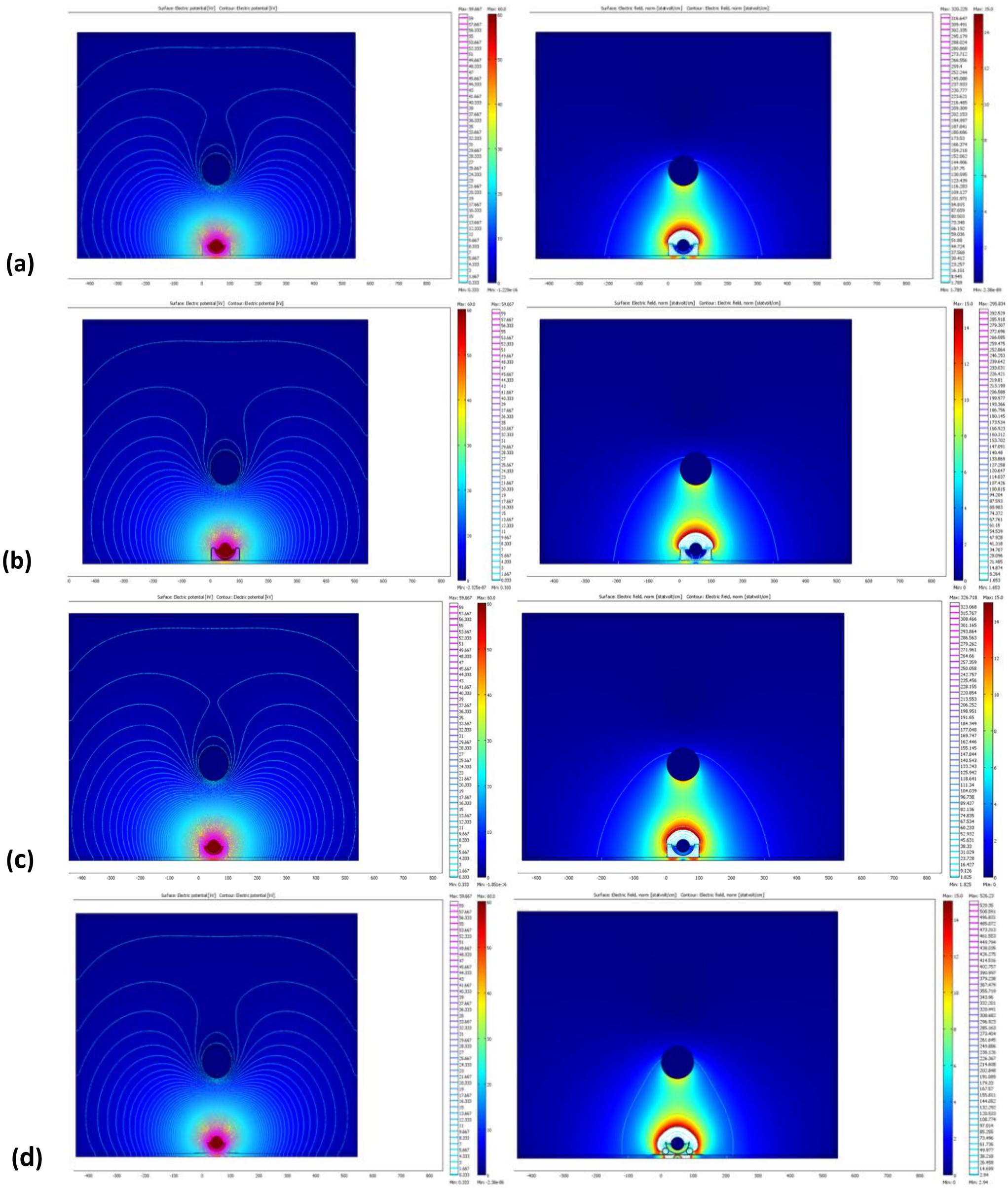

Fig. 2. Distribution potential and the intensity of the electrostatic field (a) Reservoir made from polypropylene; (b) Reservoir made from steel; (c) Reservoir made from wood; (d) Reservoir made from glass

Table 2. Permittivity of applied materials

Material	Relative permittivity
Reservoir (polypropylene)	2,3
Reservoir (steel)	1
Reservoir (wood)	4
Reservoir (glass)	7
Polymeric solution	81,6
Box - cover	3,5
External environment - air	1,00054

Table 3. FEM results of intensity for different applied materials

Time of process / Potential (10 min) (0/60kV)	Maximal intensity (statvolt/cm) 1)
Type of reservoir	FEM model
PP	320,22
Steel	296,84
Wood	329,78
Glass	526,23

1statvolt=299,793 volt

Results of the potential distribution and the intensity of the electrostatic field for the individual reservoirs are shown in Fig. 2 and Table 3. From the simulation results (Table 2) it is clear that a different sizes of the relative permittivity of the applied material have a significant effect on the intensity of the electrostatic field. The greatest intensity was reached in the reservoir made from glass.

3.3. Experiments

The results were also verified experimentally, directly on the line of the company Elmarco (Fig. 3). On the basis of structural designs, prototype polymer reservoirs were produced and used in real spinning processes (Fig. 4). The efficiency of the process was evaluated as the amount of polymer, which was spun for a period of 10 minutes. The results are shown in Table 4.

Fig. 1. Production line for the production of nanofibres

Fig. 4. Electrospinning: Application of a wooden reservoir (above), and a glass reservoir (below)

Table 4. Productivity of different reservoir

Time of process / Potential (10 min)/ (0/60kV)	Average mass of produced fibres in different positions of grounded electrode (g)			
Type of reservoir	1	2	3	4
Polypropylene	1,18±06	0,72±14	1,44±01	1,48±29
Steel	1,01±11	0,75±01	1,59±12	0,51±06
Wood	1,35±19	1,45±05	0,89±07	1,47±22
Glass	1,58±3	2,08±07	2,39±12	1,82±14

From the results of the experiments it is clear that the relative permittivity of the material and structural design have a significant impact on the productivity of the process (Fig. 5). A reservoir made of steel showed low productivity, as did polypropylene, which is normally used for the production of reservoirs, and also a wooden reservoir. On the contrary, the highest productivity was reached by a glass reservoir. The results of the experiments are consistent with the results obtained using the FEM models.

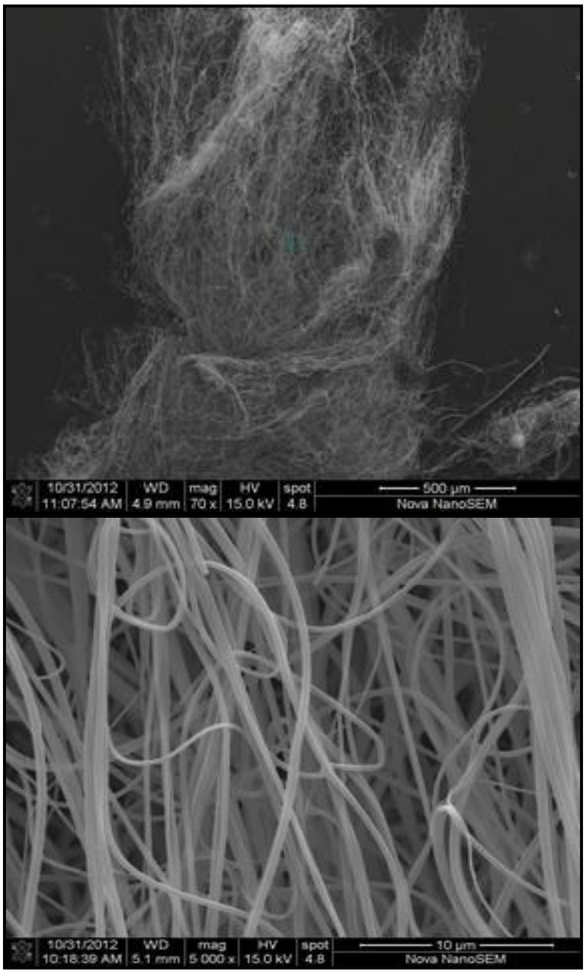

Fig. 5. Production of nanofibres (above), close up of the fineness of the nanofibres (below)

4. Conclusion

The article deals with the possibility of influencing the productivity of nanofibres produced by the electrospinning method Nanospider. Innovations in the design were achieved using the TRIZ method. The structural design was verified using a FEM model and then experimentally directly on a line of the company Elmarco. From the results it is clear that the relative permittivity of the material and structural design of the geometry of reservoir have a significant influence on the effective productivity of the manufacturing process. A reservoir made of steel showed low productivity, as did polypropylene, which is normally used for the production of reservoirs, and also a wooden reservoir. On the contrary, the highest productivity was reached by a glass reservoir. It can be said that the intensity of the electrostatic field is critical to the productivity of electrospinning and that the permittivity of the material has a significant influence on the process.

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Application of OTSM-TRIZ for definition of Engineering Process model and related deployment Strategy.

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Abstract

This paper describes the approach taken for the definition of an engineering process model and the related deployment strategy using OTSM-TRIZ within Bombardier Transportation. In 2001, we have been mandated to standardize our engineering processes across the new merged company. Due to historical growth and acquisitions there have been many processes for the same purpose, but not standard ones across all the location and factories. To align between each other, a global team has been mandated to define these set of common engineering processes. The ultimate goal has been to ensure that all our engineers are working the same way using the same set of processes. We have achieved to define a set of process in 2003 and have started to deploy this process worldwide, however after 5 years we have been still on a low level of process standardisation.
In 2008, we applied TRIZ to analyse and understand this problem situation. By applying TRIZ we understood the underlying key conflict, solved it by application of separation principles defined by TRIZ knowledge base and have redesigned our Engineering landscape. This has been resulted into a successful development of an adjusted process deployment landscape within the last years.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: OTSM-TRIZ; Network of Problems; Process Design; Process Model; TONGS Model; Separation principles

1. What is OTSM TRIZ?

OTSM is the Russian acronym for "General theory of powerful Thinking", This is an further development of TRIZ driven mainly by Nikolai Khomenko. Key concepts are "Problem Network flow, contradiction description based on the "Element – Name – Value (ENV) for solving complex problems. According to [11] OTSM tools are:
1. New Problem Technology – dedicated to settle a new problem
2. Typical Solution technology - dedicated to test opportunities to solve a problem or get partial solution for the problem by using the TRIZ and OTSM typical solution techniques.
3. Contradiction Technology – based on Altshullers ARIZ and helpful to get solutions or at least set of partial solutions and to understand the root of a specific sub problem or of a problematic situation.
4. Problem Flow Technology – helps to handle flow of sub problems that appear during problem solving process and synthesis of final concept solution out of partial solutions.
5. Based on those four technologies during last year's there

was the Problem Flow Network approach developed. This approach is dedicated to manage complex interdisciplinary problem situations and relevant knowledge for current and future needs. We have applied the initial steps by using the Network of Problems (Nofp) to model the initial situation (IS).

2. Business Objective for this study

The company has been built out of many merged companies across the world (see figure 1) resulting in a diverse business process landscape with hundreds of different processes.
The purpose of having standards sets of processes is to simply and ease cooperation between sites.

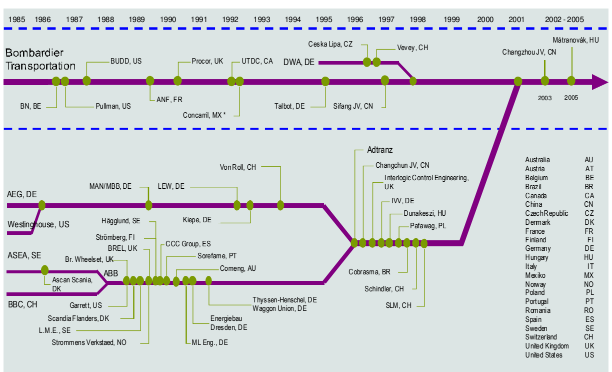

Figure 1: History of Bombardier mergers and acquisitions

3. What is the motivation applying TRIZ?

As there have been several unsuccessful approaches during the last years, we have been looking for a different approach and methods supporting the deployment of common processes.

4. The system under study

The system under study is not a"Technical system" as being defined by classical TRIZ; it is a process system or a business process model. Such models are applied in many companies as a basis for their quality and process landscape system.
Some typical known business process models are e.g. SPICE [3] or CMMI [4]. Typical parts of a process models are a set of business processes including a description of content how to execute the process steps. Audit systems are part of these models to understand the deployment and the maturity of the defined processes within a company.

5. The TONGS model

The TONGS model (see Figure 2) is one of the OTSM TRIZ tools to understand the initial situation IS and the hindering barriers.
Understanding these barriers do lead to an initial modelling of underlying contradictions. Details in using the TONGS model one can find in [1]. These barriers are related to the initial set of problems will be used as a starting point modelling the NofP as described in [1] [2]

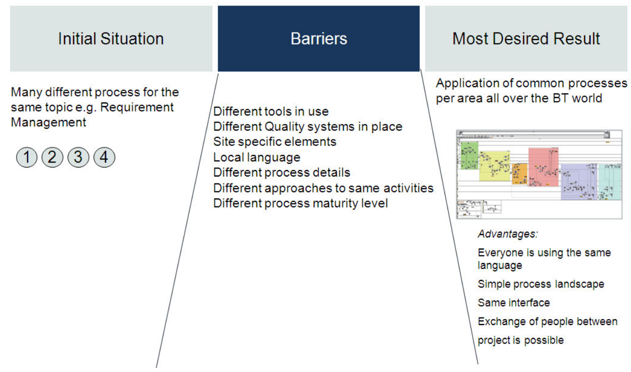

Figure 2: TONGS Model

6. The Network of Problems (NoFP)

To continue the OTSM-TRIZ Study and to understand the Initial situation the NofP is populated. It starts, as defined in [2] with a set of problems including Partial solutions. See Figure 3

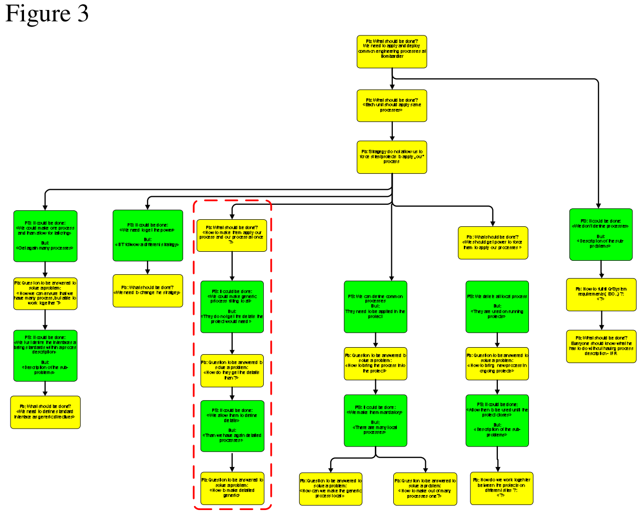

Figure 3. Network of problems of deployment for a "Engineering process deployment strategy"

Analysing the NofP, we selected with the team focusing on the conflict hindering to deploy common processes to a wide, diverse organisation.
The contradiction is defined as:
If you tell an employee to do process activities in a specific, standardized way in his local department, than he will respond to you that we do things here (locally) different and we cannot

use a standard process. If you do it vice versa not defining the details and taking the approach of degreasing the level of details with the goal to make it general fit, he claims that he does not know what to do in detail.

7. The underlying key conflict in ENV Model format

The control parameter CP1 - which is per definition the one which we can influence for designing the process landscape [1] and related deployment strategy, is the *level of details* on documentation.

The defined conflicts see in Figure 4.1 and Figure 4.2 using the ENV Model from OTSM -TRIZ

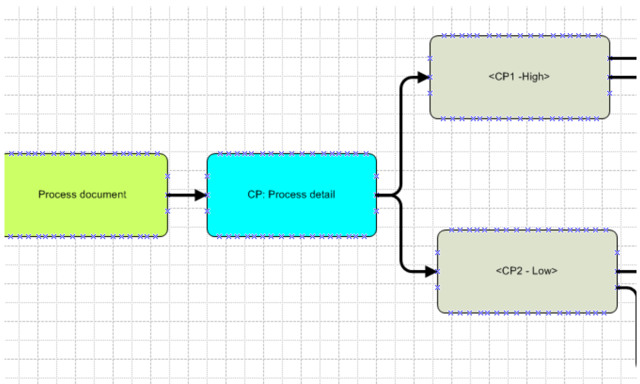

Figure 4.1: Selected conflict for process design details – left side

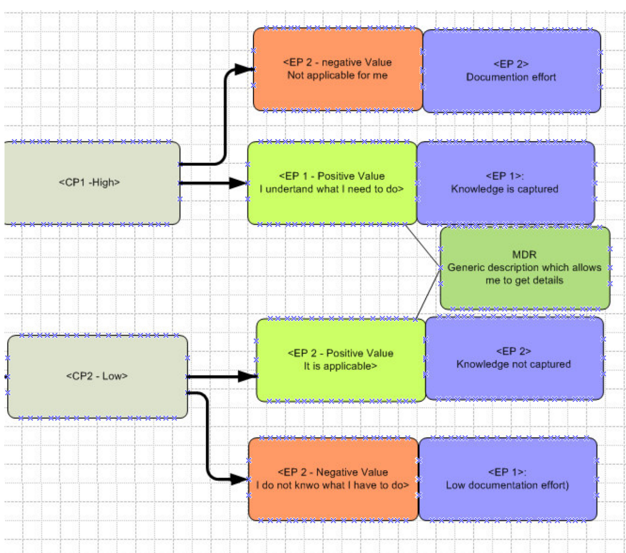

Figure 4.2: Technical contradictions for process design details

According to the OTSM ENV Model we have defined as element E: *Process document*. As Control Parameter CP: *Level of details of document.* As evaluating parameters EP: *Applicability of the process.*

Within our former 2003 design process landscape we had the setting CP1 to *"high level of details"* which has resulted in "*not applicable to me*". This has led to remaining deployment problems in the years after and not using the standard process or adapting the standard.

Nomenclature

E	Element: Process document
CP	Control Parameter
EP	Evaluating parameter

8. Solving the physical contradiction.

As in Figure 4.1 blue and grey boxes, a Physical contradiction is described: The setting of the Control parameter CP1 – process detail – *"High" (see Figure 4.2)* leads to a positive evaluating parameter EP 1 " *I understand what I need to do*". The tasks are described to a detail which can be easily executed, but on the other hand – EP2 – *"it is not applicable to me"* because our organization set-up is still different to the assumed standard and the user are doing activities different. So the process detail should be high and low at the same time.

Concluding this thought and defining the "The Most desirable result" for a process model: describe a *generic process (low details) also very specific (high details).*

Applying the separation principles – "Separation in Space" we have designed the Bombardier Engineering System 2010. The name implies 10 generic Process directives defining just the requirements on processes meaning with – *low details* - using 20 documents. Low details mean no detailed description of the activities, but describing requirements on the deliverables of the activities.

The model has been finalized in 2010.

Detailed process can be than described as a local standard by the sites and Divisions with – *high details* - fitting their needs. However if should fulfill the requirement defined in the global generic standard.

Lets describe an example about the "Verification" process. In the generic description we ask as a requirement for a "Verification schedule". This is the generic request.

How this "Verification schedule" is done on which detailed activities in detail is free.

Of course we are looking for "Best Practices" and try to share them. But we do not define the activities how this is done.

The model has been completed by using the "Principles" and "Practices" including engineering "methods". TRIZ is being part of the set of "Methods". See Figure 5.

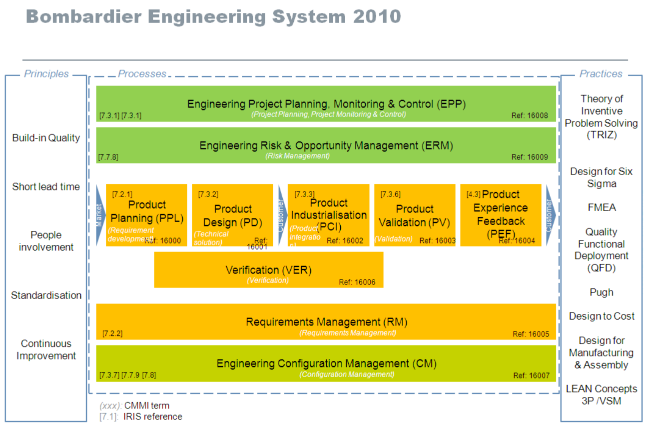

Figure 5: BES 2010 process model

In Figure 6 there is an extract from the BES Model 2010 example: Verification process.

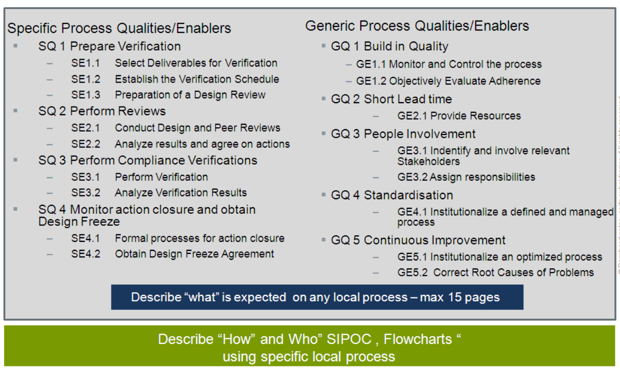

Figure 6: Specific and deployment requirements

9. Ensuring the deployment maturity by doing BES Assessment

In 2010 we have started to deploy this process model. To understand the maturity of the processes we did "Baseline assessments" by using our designed assessment method. These standardized assessments are based in CMMI [3] approaches. Since 2010 we are running Assessments. These Assessments have resulted into improvement plans. The goal is achieving higher process and deployment maturity year after year.

Acknowledgements

I would like to acknowledge the support we have got from the Vice President Mr. Yves Carton being the supporter of the BES2010 System. I would like to say thanks to my entire team from several Bombardier Divisions being part of the development team in the years 2008 into 2010.

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

Product improvement using TRIZ at Philips, a case study

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Abstract

This paper will present a case study on using TRIZ for the improvement of Consumer Lifestyle Products at Philips. TRIZ has been used at Philips for a number of years now. The present paper will show how we, typically utilize various TRIZ tools to improve existing products. Projects are typically starting with a thorough TRIZ analysis of the product, either to identify improvement areas, or to deepen the knowledge about specific problems. This is followed by a TRIZ workshop where, based on the analysis, a multidisciplinary team is using a variety of TRIZ tools to come up with a improvement ideas. Finally a ranking and selection process is used to identify those ideas with the highest potential. The talk will be amply illustrated using workshop material from the creative sessions as well as real-life examples from our product catalogue.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: TRIZ; Substance-Field Analysis; case study; idea generation; memory search.

1. Introduction

Philips Consumer Lifestyle is developing, manufacturing and producing consumer products in the areas of floor care, kitchen appliances, beverages, garment care, skin care, hair care and shaving. In the development process technical issues are frequently encountered, and for a number of years now TRIZ is used at various sites to systematically analyze and solve these problems. Over the years numerous of these problems have been solved and a way of working has been established that integrates TRIZ into the overall development process. In the following this process will be outlined and illustrated using some real world examples.

2. Analysis phase

Our development projects can have a number of different starting points. They may, for example involve the improvement of or variations on an existing product, or concern the development of the next generation of an existing product. At Philips we always aim to satisfy our customer’s needs, and any information about potential improvement opportunities that are collected from feedback with existing products may serve as a starting point.

In our development of the latest model of centrifugal fruit-juicer, for example we got the market feedback that, while customers valued the ability to get fresh fruit juice in an easy way to help them in achieving a healthy and tasty diet, the time that is needed for cleaning the juicer was seen as a significant drawback.

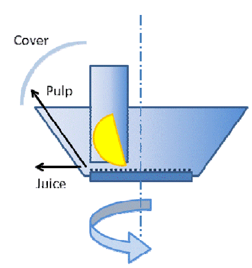


Fig. 1. The initial Juicer is shown. The fruit is grated on a fast rotating grater, and the pulp and juice are forced outside onto a sieve by the rotational movement. The juice passes the sieve whereas the pulp is thrown up towards a transparent cover and then towards a waste-container. The cleaning of the cover and waste container was identified as a key problem.

In another project, concerning a mechanical epilator, users reported that the pincers used to pull out the hair, on occasion, would catch and pull the skin - which can be quite painful. Furthermore, the product was time-consuming to clean.

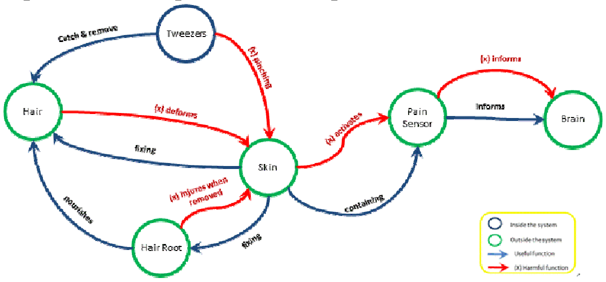


Fig. 2. Function Analysis of the epilator product

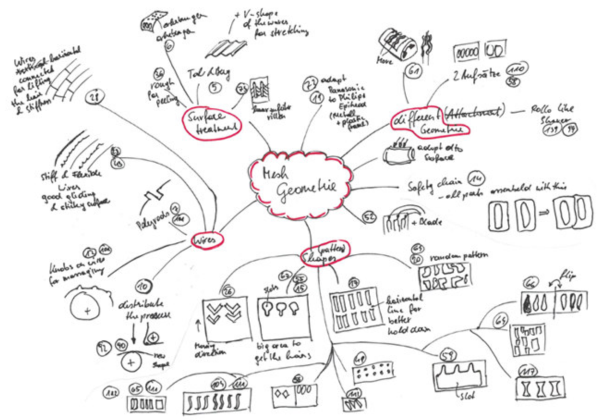
Typically we collect all available data on the project during the analysis phase in an “Innovation Checklist”. This includes general project data, the project brief, and also the results of various analysis tools such as Function Modeling (1) and Cause Effect Chain analysis (2).

3. TRIZ workshop

Once the analysis has been done, and the underlying causes of the problems are well understood, we normally assemble a group of TRIZ trained developers, marketers and other disciplines – based on the scope and focus of the project – to conduct a TRIZ workshop. During the cause of a few days we explore the solution space from a variety of different directions. Using TRIZ in such an event has a number of significant advantages:

- The strong structure helps the team to stay on track and focus on the essential elements of the investigation. For example, TRIZ concepts like ideality act like a flag on the horizon pointing everyone’s nose in the same direction. Furthermore, the fact that the result from the application of one tool is the input for the next one clarifies and speeds up the innovation process.
- A multitude of possible starting points make the full exploration of the solution space easy. For example, using Contradictions and Inventive Principles on the one hand, and Su-Fields and Inventive Standards on the other hand, will inevitably lead to subtly different evaluations of the problem and together ultimately to overall stronger solutions.
- The self-guiding nature of many TRIZ tools, as well as the simple language to communicate about problems lets people with different backgrounds, with different degree of knowledge of TRIZ and with different degree of knowledge of the problem work together seamlessly and easily.

Fig. 3. Structuring of ideas (example) generated using selected TRIZ inventive principles



4. Ranking and Selection

Ranking and selection of ideas begins already in the workshop. To aid this, a number of guidelines are formulated in the project brief and the “Innovation Checklist”, and they serve to help the workshop team to prune and combine ideas at an early stage. The most valuable ones are carried forward and developed further. In this phase TRIZ analysis and problem solving tools may be used by the individuals or development teams, if they encounter specific problems.

- In the juicer example, the winning idea emerged from the inventive principle #13 “The other way around”. The centrifugal filter, rather than pointing upward was reversed to point downwards. This causes the pulp to be collected on the inner part of the juicer and the juice on the outer part. As a result the juicer is much easier to clean, and the juicing process becomes more visual as the user can see the juice – rather than the pulp – when looking at the product in action.

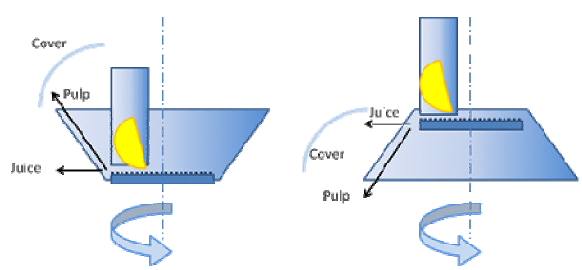


Fig. 4. Working principle of the original centrifugal juicer vs. the new centrifugal juicer

- In the example of the epilator the basic idea of the winning concept was mainly driven by inventive principle #11 “beforehand cushioning”. In the analysis phase the main direction for the solution was born by defining a physical contradiction and solving it by using separation principles. During use the epilation head should be as free-standing as possible when a hair will be pulled out and as closed as possible when skin could get in contact with the rotating epilator head discs. A bar on the backside together with the shoulders left/right from the epilator head protect the skin. The rest of epilator head was free-standing to catch all hair easily but also to get cleaned in an easy way under the tap. In previous versions the epilator head was nearly totally closed.

Fig. 5. Epilator comes with a bar on the back side to protect the skin. Rest of epilator-head is free-standing.

5. Discussion and Conclusion

We found that our product development projects gained significantly through the use of TRIZ:

- Firstly we are confident that the use of TRIZ leads to a greater variety of strong solutions to the problems that we are facing, and we can be sure that we did not overlook some obvious ones.
- Secondly we experienced that TRIZ helps different disciplines to work together in a coherent and focused manner. This is one of the reasons why we chose to not only send engineers to our TRIZ courses, but also other relevant disciplines such as marketeers.
- Furthermore, while aimed at engineering problem solving, TRIZ gives consumer needs a place in the development process.

The two product examples used in this talk have both recently entered the market. In their respective categories both products are, at the time of writing, very well received, which is reflected in a high market share. We must have done something right.

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

TRIZ in Robotic Engineering: Wall Climbing Robot Challenge resolved with PEGASUS algorithm

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Abstract

This paper presents a case-study that demonstrates how PEGASUS algorithm for inventive design helps even an un-experienced user to come up with an inventive solution. Modifications of classical ARIZ (which was done in PEGASUS) make possible the use of TRIZ by inexperienced beginner or a person who does not have intention to study new technique at all. The simplicity of the step-by-step guide does not sacrifice the main working engine of TRIZ thinking, which is not often explicitly present in publications.
The case-study presents the way of application of PEGASUS procedures to resolve a number of design challenges that appear during the development of vertical smooth wall climbing robot. Absolutely novel approach to climbing smooth vertical surfaces with negative angles and transition to upside-down position is developed. New simple mechanism to transition between vacuum/exhaust sections, which allows speeding up the rate of extraction/replacement to and from suction cups was developed.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: ARIZ, *TRIZ, robotics, climbing robot, vacuum pump*

3. Introduction

The main challenge in introducing TRIZ to companies is to prove that TRIZ system is applicable to the domain of a particular industry: successful TRIZ case-studies do not convince that TRIZ would be useful for others, “test-drive” of TRIZ is in a great demand. So, there is a contradiction: people need to know TRIZ before they use it, but they do not want to learn TRIZ before they understand that TRIZ works for them. Existing TRIZ education still needs a personal supervision and support in understanding the system – online courses are either too simple to be practical or too complex to be doable. Contemporary ARIZ developed by G.S. Altshuller [1] is usually presented at the very end of all TRIZ courses, because using it absolutely impossible for beginner. Our users (mostly students) are beginners by definition, they need to see TRIZ in action immediately. We decided to resolve this contradiction creating the simple algorithm to address a challenge presented in seven videos called PEGASUS guide for breakthrough ideas and an "Inventor's Manual" [2] to accompany the videos. The algorithms we present in the video and the manual are based on TRIZ, but there is no need to know TRIZ to be able to use them. Different TRIZ tools that may assist in the process of problem-solving can be learnt and used later where, when and if they are needed.
The following features make the PEGASUS Inventor’s Manual unique:

- Step-by-step problem diagnostics and templates for defining the Ideal Final Result, which are not presented in ARIZ at all.
- Templates for thorough reflection on the context of a product design that are not explicitly presented in ARIZ and TRIZ at all, but which are very important system thinking aid techniques especially if we are dealing with complex engineering or social system.
- "Shortcuts” and cross-links in the systematic process that allow to resolve challenges instantly using simple templates.
- Inventive Principles have detailed descriptions in connection to the model of the inventive challenges they resolve. This is not presented in any publication on TRIZ.
- There is an influence of natural rules for dealing with resources, complexities and ways to avoid problems that are

not present in classical TRIZ methods at all.
Inventor's Manual together with its video-companion PEGASUS (www.triz.technology, www.triz.guru) was verified in teaching TRIZ at the University of Bath, where students were given the opportunity to apply this algorithm in their final year project design. One of the most successful projects is presented in this paper.
The aim of the project was "Re-designing the wheel - to create a novel vacuum wheel for climbing robot. Robotics as a cross-disciplinary domain needs methods and tools for resolving issues that emerge due to incompatibility of some requirements or conditions – it is ideal test-area to challenge the PEGASUS tool.
There are a number of challenges to be addressed with TRIZ in this project.
The first challenge is that as wheel rotates the suction needs to move with the correct suction rubber cups and the system should "know" which cup is the one to operate (attach and detach when and where it is required).
The second issue is that the robot needs to travel between different planes: climbing up the smooth wall it meets the requirement to travel not only vertical surface, but also a surface with negative angle - robot eventually faces the ceiling and needs to transfer itself into upside down position. How can suction location be quickly taken to where it is needed? A good example of a surface with negative angles is inner surface of a cupola or an arch.
The third challenge was caused by ordinary design of circular cups. Circular shape is not suitable when the cups need to arrive at an angle like they would in the case of a wheel design. This means that we need to change the design of the cups to resolve this issue.
Applying PEGASUS we resolved these design contradictions and a new design of vertical smooth wall climbing robot was suggested. Novel wheel concept integrates the advantages of low friction rolling motion (as a wheel) with vacuum suction to enable robots to climb walls and other high inclines. Design integrated the equivalent of a suction pump and valve system to control the timing and location of the applied suction.

2. PEGASUS algorithm to resolve climbing robot challenges

An inventive challenge never looks trivial and very often seems impossible. This aspect confuses students and they always need templates for thinking in TRIZ manner.
The PEGASUS algorithm breaks down the fundamental inventive mindset into seven stages, which are taken as the main guide for development of an inventive solution. Each takes through a series of questions that lead through the process. Working through key objectives (Stages 1 and 2), defining the context of a challenge (Stage 3) helps to clearly formulate the essence of the problem, by relating statements of what should be achieved and what stops it (Stage 5). Resolving this contradiction (Stage 6) using available resources (Stage 4) is at the centre of the process. Conceptual solutions may appear at each stage of the algorithm, so at the end we choose the best one and even generalize it into a method to make the most of it (Stage 7). Each stage has a detailed questionnaire to follow.

2.1. Stage 1. Defining a challenge

A perception of the problem may yet be very unclear; we may even not see any problem at all. Challenge may be expressed in different ways and this may lead to development of different approaches to the challenge while coming through the problem-solving stages. A user needs to be sure that the challenge he/she is going to resolve is precisely the one, which should be addressed. It should be clarified why any other existing methods to resolve this challenge are not suitable. Clarification of the statement of a challenge starts from questioning the reasons for why there is a problem, who needs the solution, and what for. It is necessary to re-examine what drives people to consider this problem, why it matters, in which contexts it applies, and what are the assumptions. The aim of this stage is to reveal existing alternative options for solutions. Considering the challenge of climbing robot, the reasoning at this stage is the following:
Existing Solutions. Many robots can climb walls. However they aren't truly remote, as they require a constant flow of power/compressed air supply. Their range is limited by cable length. It would be possible to just make cable length as long as necessary for the application. Some skyscrapers (one of the fields of application) however reach heights of over 300m. Power/compressed air supply cables this long would be undesirable and ineffective. It is desirable to have a pump onboard.
The nature of the challenge is:

- Applying suction to a suction cup takes time.
- Ensuring suction is applied to the correct cup (even when going from plane to plane).
- Releasing suction from trailing cup needs to happen quickly.
- System is more stable if the pump does not rotate. *Need to invent a suitable interface between pump and rotating suction cups.*

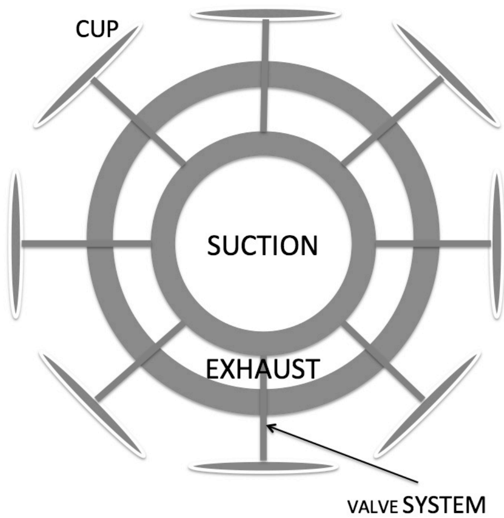

Fig. 1. IFR achieved with concentric exhaust and suction design.

Describing the Problem in Functional Terms. It is well known that functional approach helps to eliminate the impact of our assumptions about certain nouns. Required Functions are:

- Suction location & timing.

- Peeling off of trailing cup.
- Pump to remain stationary relative to the surface.

Undesired Functions are:

- Bounce of axle as wheel goes from cup to cup.
- Loss of suction due to surface imperfections.
- Exhaust and suction channels from the pump to rotate (in accordance with the wheel's rotation). These two points are in conflict.

Conflicts are to be taken advantage of in TRIZ. It is important to not avoid conflicts in the system. They are the space for innovation.

2.2. Stage 2. The Ideal Final Result

After the definition of a challenge we need to start from the end: from the solution itself. When we have to solve a problem we are usually interested in a single perfect solution - which was set as a goal. The solutions develop in the process may come close to the ideal result or even achieve it. Aiming for numerous solutions often is not efficient and sometimes can even be dangerous in critical situations. Ideally, all useful functions should appear by themselves and all undesirable effects should eliminate themselves naturally.
The Ideal Final Result (IFR) should be stated in an abstract functional way stating the result of the desirable activity or process instead of describing the things or objects.
The best result is free, where everything should work by itself, naturally. The best solution for a problem is its absence.
It is important to face the constraints at this point. Some constraints may not be real but our own mental inertia.
Applying all above to the climbing robot design challenge, we see that in an ideal case, the system:

- 'knows' where the surface is
- directs naturally suction to the cup, which is in contact with the surface
- exhaust flow from pump to trailing cup (wherever it may be on the wheel) facilitates peeling off
- vacuum "locks" itself in the necessary cup once suction achieved.

Conditions for the Ideal Final result are:

- the result is no longer needed (we applied this to control)
- the result is achieved without the system (we applied this to control)
- the function appears only where and when it is needed: suction appears immediately only as and when needed and exhaust appears immediately only as and when needed
- the system consumes minimum resources or uses resources of the whole system
- every output of the system is used – the system does not produce harm or pollution.

This lead us to the idea: what we really want is for suction and exhaust to be present everywhere, at all times, but only to act when called upon. To arrive at continuous, smooth motion cup-to-cup, surface plane to plane. It's a result of the function. We need quick transition of vacuum/exhaust from cup to cup as the wheel rotates. This will give dynamic, smooth rotation. So, The Ideal Final Result on functional terms must comprise:

- vacuum appears immediately only where/when it's needed
- exhaust appears instantly only where/when it's needed.

Having stated the IFR without constraints we can now more clearly assess what is stopping it from happening. It appears that real problem is that jumping between vacuum/exhaust takes time and therefore inhibits dynamic motion.
What is stopping us achieving access of each cup to both vacuum/exhaust chambers is the orientation of the pump to the cups? Continuous access of all cups to both exhaust and suction from the pump may be achieved with a design as shown in Fig 1.
Rather than constantly control the location of the suction and exhaust flows from the pump, let the cups call upon the pump as and when needed. This can be achieved with the aid of the environment by using sensing valves in each cup so the system 'knows' when and where suction is required! Allow the environment to take autonomous control!
This also means that the robot's wheel could make transition seamlessly onto different planes! Remaining problem: How could system 'know' when vacuum is achieved and it's safe to release previous cup?
Furthermore, 'knowing' which is the previous cup? It may be possible to have a pressure sensor in each cup to detect when vacuum has been achieved in the leading cup. This could somehow trigger the release of the previous cup! The solution is achieved even after the right formulation of the Ideal Final Result.

2.3. Stage 3. Context of a challenge

We need to investigate the problem in various contexts, where the problem may surface, and check for the conditions, which could make the desirable result possible. Conditions under which a problem does not have any chance to appear is what we should look for. This will also help to develop the most effective solution strategy.
Now we need to focus attention on the objects rather than functions, answering the questions: What is the object that generates a harmful function? In what context, under what conditions, does the harm disappear?
It is well-known that minimum number of system elements is two. This leads to elementary system model as *Subject-Action-Object.*
Considering the results after localizing the problem and revealing two main elements that generate harm, there is a very limited number of things that could possibly go wrong. In fact there are only three main causes for any problem:

1. the Object's properties are harmful
2. the Subject's properties are harmful
3. The action field is insufficient or harmful for the Object or/and Subject
4. Any combination of these types of failures are also possible.

We need to list the elements, which are involved in harmful, missing, in insufficient functions and create pairs described above (Fig 2).
List of Elements in a system in climbing robot project. Figure 2 shows the system and its context and the hierarchy of sub-, sub-sub and sub-sub-sub systems. Interesting to note that the motor system is independent. Maybe it could be incorporated somehow to benefit another function?
Exploration of the Elements in the System using *Subject-Action-Object template* in climbing robot challenge looks

like:

- Sensing Valve → Calls Upon → Vacuum
- Exhaust flow → Diverted to → Trailing Cup
- Cup Surface → Triggers → Sensing Valve
- Motor → Rotates → Wheel Pressure Sensor
- Wheel Pressure Sensor → Triggers → Exhaust to trailing cup.

The last statement is where the problem lies. We put this statement in the central box of the Nine Windows Template (Fig 3).

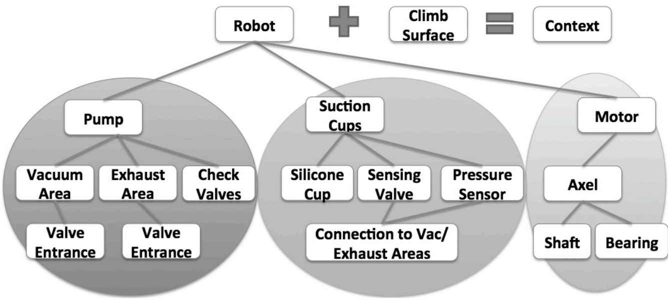

Figure 2: Graphic showing hierarchy of the system and sub-systems.

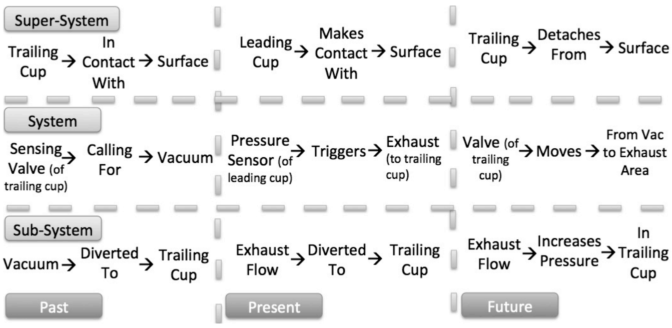

Figure 3: Graphic showing the Nine Windows for the initial process.

The Nine-Windows application as shown in Figure 3 is a critical part of the problem-solving process. It was carried out to better our understanding of the problem's context. The key problem is in the centre of the grid and its surrounding super- and sub-systems, both in the past, present and future are detailed.

From this graphic it is obvious that the Future of the System level is an area under which the problem doesn't have to appear. Considering the conditions under which the problem doesn't appear we formulate an idea: what if the valve doesn't have to move from the vacuum, to the exhaust flow but all valves are naturally at the exhaust flow. They are pushed (by sensing valve) into vacuum flow but spring back to exhaust when vacuum is no longer the desired function! This reduces the number of functions - *we no longer require control of when to apply vacuum and exhaust Control is needed just when to apply vacuum*. Now we have one more solution that perfects the design.

2.3. Stage 4. Resources

Resources are needed to create the conditions in which the Ideal Final Result becomes possible. If the project requires a lot of resources (material, time, money, etc.) then it is a wrong path!

The resources for change include the properties of objects that are available in the problem area, just like the heaviness of a hammer helps us to hit a nail into the wall. Even the object that causes the problem can be used as a resource.

Systematic considering subtle changes to the parameters of all parts of the system at hand including "free" environmental ones (gravity, air, sunlight, wind and their combinations) we need to follow the template:

"Changed/used natural properties of an objects and actions create the conditions for the Ideal Final Result". There are six categories of properties: Substance, Structure, Space, Time, Energy and Information. Full description of each category is presented in the Inventor's Manual [2]. In the climbing robot challenge we used the properties of the cup and the wheel.

Development of the conditions for the Ideal Final Result using the resources. Since the problem of controlling exhaust flow has been eliminated, how do we now make the transition from vacuum to exhaust as quick and as seamless as possible? There is also still the problem of lost energy. We will address it at the next stage of the PEGASUS algorithm

2.4. Stage 5. Contradictions

Searching for and tackling contradictions leads to breakthrough design. All previous stages helped us to define the exact location and time of the problem and allocate all the available resource for changes. Now we need to state clearly what exactly does not allow us to modify the resources in the desirable way. The conflict between those properties of an object we need to improve and those properties that do not allow such an improvement represents the model of the problem. At this stage we need to formulate the central contradiction(s) underlying the problem by identifying clearly what exactly stops from achieving the objectives: the obstacle(s). Figure 4 shows that energy is lost in the transition from one cup to another. When there is only one cup in contact with the surface, vacuum energy is not being useful. Similarly, the exhaust is not being useful then it's not helping a trailing cup release from the surface. This is all lost energy.

Localising the Obstacle - When/Where/How?

The mechanical triggering of change of valve location from vacuum to exhaust may be slow and therefore delay the wheel's rotation. Transition needs to happen instantly.

The application of the vacuum will also take time although this may be mitigated by having the sensing valve in an advanced position so that the system knows when a surface is coming up and can start applying the vacuum a moment before the cup makes contact.

1. Sensing valve calls for suction.
2. Valve moves from exhaust to vacuum.
3. Vacuum applied to cup draws out air.
4. Pressure difference created and suction to the surface achieved.

Detaching and attaching of the cup - steps 2 and 3 described above and shown on figure 4 need to be as fast as possible.

Obstacles and limitations are:

- time delay inherent in mechanical system
- a potential for jamming of sensing valve movement or of valve head movement from exhaust to vacuum.
- a diaphragm's effectiveness is limited by small contact area between vacuum/exhaust rings. This obstacle would be

minimised if we could increase contact surface area between the two rings.

- the speed of the wheel is limited by structure of system.

Physical Contradiction:

We want to use all of pump output effectively. It's only required at certain times. We cannot turn pump on and off between when it's needed and when it's not as this would be too slow process. Pump should be on *and* off permanently.

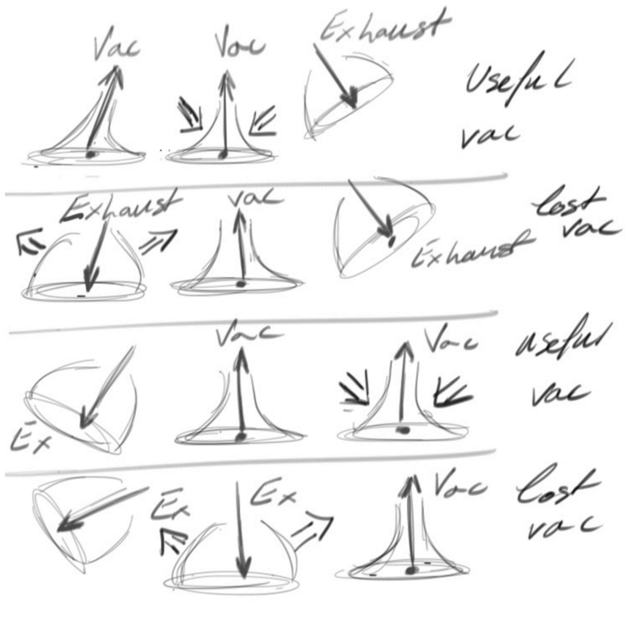

Figure 4: Diagram showing timings of lost energy.

Technical Contradiction:

As we increase the speed of the robot wheel, the risk of failure of the mechanical system increases. Risk of 'bumpy' motion increases also.

Use of X-factor:

X-factor is an imaginary part that could idealistically solve a remaining problem at this later stage of the process. In this case, an X-factor would mean vacuum/exhaust energy not lost when it's not being used. An X-factor would store the energy for when it's required. Able to therefore release energy in a larger magnitude when it is called for to make suction/release of cups happen with less time delay. X-factor would: integrate into system and would not interfere with valve network (increasing risk of failure/jamming).

Solution! X-factor could be a kind of capacitor for pneumatic pressure. It would be like a diaphragm between the vacuum and exhaust rings. It could contain the loading of increasing and decreasing pressure in the vacuum and exhaust rings. If we remove the space between the two rings and position the diaphragm as an interface between the rings then it could oscillate between the two sections. In this way, as volume of exhaust section increases, vacuum section decreases in volume. This would work since, as shown in Figure 4 exhaust and vacuum sections are called upon alternately.

2.5. Stage 6. Solutions

Now we are at the final solution-finding stage and need to isolate the contradicting properties using Separation Principles in order to eliminate the key conflict. To develop the conditions for the Ideal Final Result we need to modify the properties of the obstacle (subject, object, action or environment) using the Inventive Principles. If we have an explicit technical contradiction we use the Contradiction matrix.

We used the BioTRIZ Expandable contradiction matrix [3] to resolve the following challenge: our robot needs to travel between different planes: climbing up the smooth wall it eventually meets the ceiling and transfer into upside down position. How can suction location be QUICKLY taken to where it is needed? The technical contradiction is the following: increase the speed of the robot wheel, the risk of failure (reliability) of the mechanical system increases. For example, we want to improve the 'action duration of moving object'. But what gets worse if we do this is reliability. Inputting these contradictions into the contradiction matrix we arrive at inventive principles: 11, 2, 13.

№11 - "Beforehand cushioning" means to be prepared for low reliability. Arms supporting the suction cups to the centre of the wheel could be flexible and dynamic, for example they could be concertina-like shape. This could mitigate the bumpiness of the motion of the wheel as it goes from cup to cup.

№2 - "Taking out" parts, which are not involved in main function. Make mechanism as simple as possible. Compressed air may be taken out... Could we just expose trailing cup to atmosphere to release pressure? Time testing would be required to see if it's fast enough.

№13 - "The other way round". Make movable parts fixed, make fixed parts move. What if valves don't move to vacuum/exhaust chambers, but the chambers move to them? Moving heads around the perimeter of chambers. How could this be achieved? This is a good question that may lead to another invention.

One of the issues we mentioned at the beginning of the paper was caused by ordinary design of circular cups. Circular shape is not suitable when the cups need to arrive at an angle like they would in the wheel design. This means that we need to change the design of the cups to resolve this issue.

So, there is a further contradiction. We wish to improve the speed of changing the pressure inside the suction cup. Therefore as we improve 'Deficit of time 'area of moving object' stops us - a cup which arrived in angle does not have full contact with the surface. The contradiction matrix gives inventive principles 10, 35, 17, 4.

№4 - "Asymmetry". Why do the cups need to be conventional and round shaped? Why not design them to be more efficient for this application? - See Figure 5.

№17 - "Another Dimension". To increase the surface (contact) area between the vacuum and exhaust chambers (meaning the area and therefore effectiveness of the X-factor diaphragm) one could re-arrange the orientation of ring like design from a 2D one as shown in Figure 1 to a 3D design as shown in Figure 6. It is a multi-layered, disc-shaped design inspired by inventive principle №17. It is also copying the optimum shape of red blood cells. Red blood cells have the best possible surface area to volume ratio for best possible oxygen absorption.

This design also allows for a chamber to move instead of a valve head (inventive principle number 13), which resolved the first contradiction we considered. A switch could flick between the two chambers. Perhaps spring-loaded (inventive principle number 10)? Hydraulic? Pneumatic (changing the parameter of acting medium - "Parameters' change" - inventive principle number 35?

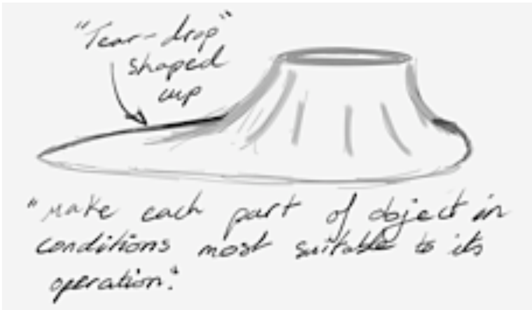

Figure 5: A teardrop design for a suction cup.

Climbing robot design must integrate the equivalent of a suction pump and valve system to control the timing and location of the applied suction.

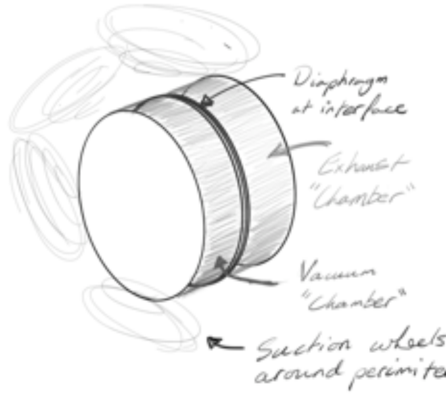

Figure 6: Disc design from Principle #7.

A number of design ideas came from the previous stages of the PEGASUS algorithm, some of them are from the direct application of the contradiction matrix. The designs that would be implemented are as follows:

• The tear-drop shaped suction cup (or other variation). It is clear that circular cups are optimised for perpendicular contact. Not optimised to arrive at an angle like they would in this wheel design with tear-drop cups.

• The telescopic suction cup arms with suspension will most certainly be further investigated as a means of reducing or even eliminating bumpy motion from cup to cup.

• The use of a hydraulic system in place of a mechanical one will certainly be preferable to increase reactiveness of system.

• The Ideal Final Result as detailed in Subsection 2 is achievable.... Multi-layered chamber design are preferable to ring design. Larger diaphragm to mitigate energy loss through pump overflow valve - this would also mean higher-pressure difference to speed up rate of air extraction/replacement to and from suction cups. IFR ACHIEVED! It also allows a much simpler mechanism to transition between vacuum/exhaust sections. Climbing robot design must integrate the equivalent of a suction pump and valve system to control the timing and location of the applied suction.

2.6. Stage 7. Solution revision. How would system change? New applications?

With a variation of parameters would the system change much and would it potentially have any new applications?
What if the environment was changed from air to water? Pneumatic pump changed for a water pump. Valve network made to work underwater. Motor sealed in water-proof casing. This new robot could be used to navigate around the inside of glass aquariums! Used to navigate the inside of large liquid vessels and check the wall surface quality from the inside?

Conclusions

Robotics as a multi-disciplinary domain needs methods and tools for resolving issues that emerge due to incompatibility of some requirements or conditions. The PEGASUS algorithm helps even un-experienced user to come up with inventive solution. The simplicity of the step-by-step guide does not sacrifice the main working engine of TRIZ thinking, which is not often explicitly present in publications.
Each stage of PEGASUS algorithm can lead to a workable solution. This is exactly what happened in current project - the first solution was developed at Stage 2, then additional perfection at Stage 3 and finally inventive solution appeared at Stage 4.
Absolutely novel approach to climbing smooth vertical surfaces with negative angles and transition to upside-down position is developed. The main mechanism of the robot is based on rotating wheel, which is covered with suction cups that are connected to a suction pump, allowing the suction cups to stick to the surface. As wheel rotates driven by motor, the cups that contact with a surface call for vacuum to be applied to them. Cups that are peeling off the surface call for the pump exhaust flow, which will release the low pressure inside the cup and let them unstick from the surface.
Applying PEGASUS algorithm we came up with the design that resolves the issues mentioned above allowing much simpler mechanism to transition between vacuum/exhaust sections, speeding up the rate of extraction/replacement to and from suction cups. The teardrop asymmetrical shape of the suction cup is also suggested.

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

TRIZ-based Patent Design Around for Enterprises: An Innovative Redesign of Pencil Extender Device

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Abstract

Patent design around is crucial to the enterprises' product designing and technology innovation. A patent-around innovative design method based on TRIZ is proposed in this paper. The method includes the following two features: (a) using function analysis to anaylze the existing patent providing the process for the enterprises' in-depth analysis of patent documents from the perspective of patent-around, (b) combining TRIZ problem-solving tools to the around strategies to find out the relationship between them, thus to provide a guidance for enterprises' technical engineers and designers to utilize suitable TRIZ problem-solving tools, when they want to solve the problems arosing from using the patent around strategies. The proposed method may help small and medium enterprises improve their designing ability. Especially for those who are not familiar with TRIZ theory, the proposed method would help them utilize TRIZ theory effectively for patent-around and product innovation design. Finally, the method is tested and verified successfully by a case of a pencil extender device. In this case, the patent around strategy of deletion and substitution method is used, then corresponding TRIZ problem-solving tools, contradiction matrix and knowledge-effect database are applied to solve the problems. By using this approach, we can accomplish a new design-around product which is much more convenient than the previous one .

Keywords: TRIZ; patent design around; pencil extender device; innovative design.

1. Introduction

As the intensification of economic globalization and market competition, enterprises' demand for product innovation is becoming more and more important. There are various approaches to realize product innovation design, but they all need the support of existed knowledge and experience. As the patent knowledge is associated with the characteristics of advance and timeliness, it is the most effective carrier of the technical information and can provide great realistic significance for enterprise innovation [1].However, the enterprise often encounter with patent barriers when they are tring to take advantage of patents. Enterprises should establish conscious of patent strategy to overcome such problems.

Patent-around design is one of the most important activities of patent strategy. Initially, it was the America's legitimate competitive behavior and only used as a passive protective measure when their products are accused of infringement [2, 3]. But now patent design around is a kind of active defense and offensive strategy, and is helpful for enterprises undertaking invention activities. TRIZ is the Russian acronym for Theory of Solving Inventive Problems, was founded in 1946 by a Russian engineer and scientist, Genrich Altshuller [4]. TRIZ is an effective method to analyze technical system and solve technical problems involved in invention activities.

At present, some researchers have proposed several approaches for TRIZ-based patent design around [5, 6, 7, 8]. Many of them have given general process of patent design around, which may guide technicians to carry out patent design around to some extent. However, they did not give a detailed description for the application of TRIZ, for instance, how to apply function analysis method to the patent analysis, or how to utilize TRIZ problem-solving tools after choosing around strategies, which may hinder the enterprises (especially for those small and medium enterprises who are not familiar with TRIZ theory) to design around.

Based on the research of others, TRIZ function analysis to analyze patent is proposed, and the relationship between patent around strategies and TRIZ problem-solving tools are revealed in this paper, thus to assist enterprises and designers of conducting product innovative design more easily and effectively

2. Patent design around method based on TRIZ

2.1. TRIZ Theory

Based on the study of the worldwide high level invention patents， TRIZ theory is a complete theoretical system of innovative method. Since TRIZ was derived from the patent, it is also an effective tool of patent analyzing and can provides a systematically and revolutionary way for problem-solving. The theoretical framework of TRIZ is illustrated in figure 1 [9].As shown in Fig.1，TRIZ is a versatile theory for problem formulating, system analysis, contradiction solving, etc, and a tool which can help technical technicians of enterprises improve their efficiency of innovation dramatically.

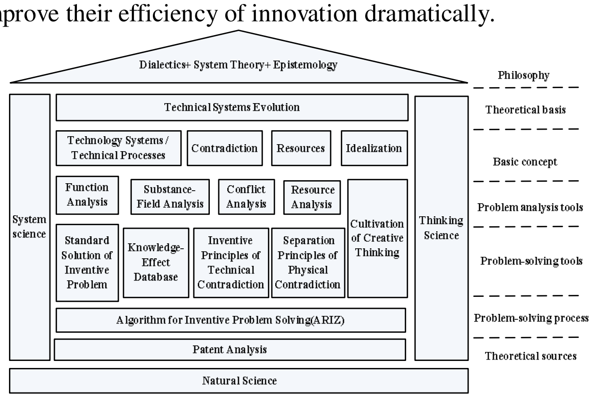

Fig. 1. Theoretical framework of TRIZ.

In this paper, the main tools used for patent-around design are the function analysis and the problem-solving tools. The function analysis is used to analyze the existing patent, and then the problem-solving tools are combined with patent around strategies for solving the innovation problems and designing a new product which is different to the existing patent.

2.2. Methods of TRIZ-based Patent-around innovative design

Generally, the process of TRIZ-based patent-around innovative design is mainly composed of the following four steps [10]:

- Step1: Searching and analyzing the related patents to excavate the core technology of the studied product and identifying the target patent.
- Step2: Using function analysis to analyze the target patent. Obtain the thinking direction of patent-around according to the function model.
- Step3: Using patent-around strategies and TRIZ problem-solving tools to find the innovative breakthrough and forming the design concept.
- Step4: Refining and optimizing the design concept to develop a new product and utilizing patent infringement for a infringe judgment.

In this paper, we will focus on the depth analysis of the target patent by using function analysis, and build a function model to clear the advantages and disadvantages of target patent. Moreover, for the target patent which has been analyzed, this paper proposes some suggestions for using TRIZ innovative problem-solving tools after adopted patent around strategies so that the technical technicians can conduct innovation activities more quickly and efficiently. And this is the main contribution of this study to others.

2.2.1 Patent analysis through the function analysis

Before patent analysis，enterprises should orientate the market and formulate patent searching strategy. The patent searching should focus on the inventive and new practicable patents for these patents implying the core technologies. Through a specific analysis of searched patents, one or several core patents are identified as the target patent.

The next step is analyzing the target patent and establishing a function model. Function analysis is an important tool of TRIZ for system analyzing, and its main purpose is to transform the abstract system into a figure , to help the designer understand the whole technology system and its problems more easily. The function model could help designers simplify a complicated system and conduct innovative design appropriately. Prior to this, the “interaction matrix” over the system and super system components shown in Table.1 can be established to identify and describe the interaction between system and super system components, thus to help designers create the function model of the target patent.

Table. 1. Component interaction matrix.

	Component 1	Component 2	......	Component n
Component 1		—	+	—
Component 2			—	—
......				+
Component n				

"+" indicates there is a relationship between two components
"-" indicates there is no relationship between two components

During the process of establishing function model of the target patent, we must also analyze the patent documents, especially the independent claims and implementation methods, which will help us to identify the key components that may be avoided. Afterwards, combine this with the function model to identify the direction of patent-around. The patent analysis process based on functional analysis of TRIZ is shown in fig.2.

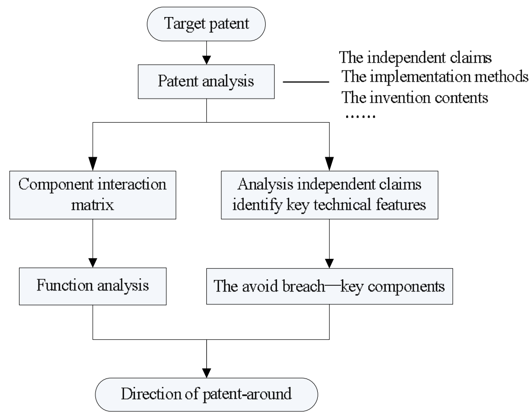

Fig.2. The patent analysis process based on functional analysis of TRIZ.

2.2.2 Combination of design around strategies and TRIZ problem solving tools

After establishing the function model of the target patent, the next step is to use around strategies and TRIZ problem-solving tools to design a new product.

From Fig.1, the tools used in problem-solving phase include Standard Solutions of Inventive Problem, Knowledge-Effect database, Inventive Principles of Technical Contradiction and Separation Methods of Physical Contradiction. The standard Solutions mean that very similar problem model of different problems have the same solution model. They are used in problems which consist of two or more undesired interactions between subsystems, and providing solutions for those missing, inadequate, excess or harmful situations. The Knowledge-Effect database is a problem-solving tool based on the knowledge, and its application is by using the relevant knowledge of this field or other field to solve problems in design process. Inventive Principles represent a set of good ideas ready to be used, they are suitable for the technical conflict problems which are easily described by 39 engineering parameters. The application is not particularly complex and usually it comes in combination with the Contradiction Matrix. Separation principles are applicable for those physical conflicts which hide more deeply and intensely, the core idea is to achieve the separate of the contradiction between two sides.

At present, the general patent around strategies mentioned in the literature are the deletion, substitution, combination and decomposition method and exclusion feature substitution method. The exclusion feature substitution method involves searching history of patent application and follow-up procedures, which is not related with innovative design, so here we will not discuss it.

After around strategies being applied to the functional model, usually there will get some new problems. To solve these problems, technicians generally seek for TRIZ tools which are mentioned above to solve the problem, the process is complex and aimless. Here, the paper combine the around strategies and problem-solving tools, give the corresponding optimal problem-solving tools for each around strategies to provide some guidance and advice for enterprises to solve the problem.

Deletion means to reduce the number of elements in the claims to satisfy the all elements rule. In this way, contradiction or function loss is often apparent, then the problem could be converted to a technical or physical contradiction. In such circumstances, Invention Principles can be chosen to solve technical contradictions and the Separation Principles, Substance-Field Model and Standard Solutions, Knowledge-Effect Database to solve the physical contradictions.

Substitution means to replace some components with other components by using different methods (technology, method, principle) to achieve the same function and effect of the original system. Substitution is to satisfy the all elements rule and the doctrine of equivalents. If adopted this strategy, use the Knowledge-Effect Database to search other areas and find out solutions.

Combination and decomposition refer to the combination of one or more technical features of system, or use a number of new features work together instead of one feature of the original patent claims to achieve the required functions. Combination and decomposition is to satisfy the all elements rule and the doctrine of equivalents. Knowledge-Effect Database may be considered as a good tool of finding resources and solutions in this way.

The results of the analysis described above are summarized in table 2.

Table. 2. The combination of patent around strategies and TRIZ problem-solving tools

Patent around strategies	The graphical expression Of around strategies	The avoided patent infringement	Recommended TRIZ problem-solving tools
Deletion	$A+B+C+D \rightarrow A+B+C_1$	the all elements rule	Invention Principles Separation Principles Substance-Field Model Standard Solutions Knowledge-Effect Database
Substitution	$A+B+C+D \rightarrow A+B+C_1+D_1$	the all elements rule the doctrine of equivalents	Knowledge-Effect Database
Combination and decomposition	$A+B+C+D \rightarrow A+B+E$ $A+B+C+D \rightarrow A+B+C+D_1+D_2$	the all elements rule the doctrine of equivalents	Knowledge-Effect Database

The conclusion given above is just a suggestion, we can also look for other tools when using the recommended TRIZ tools can not solve the problem. After getting the conceptual scheme of the around design, the next step is to refine and complete the whole design of the new avoided product. Of course, patent infringement check is necessary both in the design process and after the design is completed.

3. A case example——The circumvention of a pencil extender device patent

The pencil is a kind of tools for writing and drawing, its biggest advantage is that the correction can be easily and repeatedly erased, but it also has the disadvantage of fast using. In particular, each pencil always remain a section of pencil head, which are all thrown out because of the inconvenient of using, and thus resulting a waste of resources. Therefore, the invention of the pencil assist device has became the needs of today's society. Now we will use the method proposed above to design around.

Firstly, we should search and analysis the related patents to excavate the target patent of the pencil assist device. Through the keyword and IPC searching, as well as reading and analyzing the documents of each patent, ultimately we determine "a pencil extender device" (CN 102381083 [11])as the target patent.

Then, analyze the target patent by using the process proposed above. After reading and analyzing specific content of the patent, we find that there are five key components, which also are the key technical features of this patent. They are 1-extension pipe, 2-screwed sleeve, 3-pushing rod, 4-convex ring and 5-clamping piece respectively, as shown in fig.3.

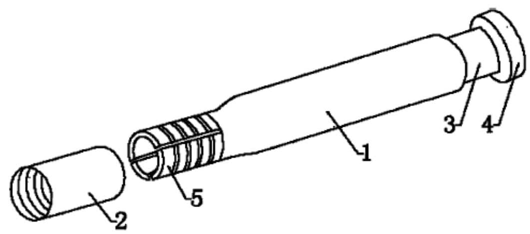

Fig.3. The structure of the pencil extender device

Analyze the patent over all system components and super-system components, and the relationships between each other of them, then establish the components interaction matrix, shown in Table 3.

Table 3. The components interaction matrix of the pencil extender device

	pencil	extension pipe	screwed sleeve	pushing rod	convex ring	clamping piece
Pencil		—	—	+ (push)	—	+ (clamp)
extension pipe	—		—	+	—	+
screwed sleeve	—	—		—	—	+ (press)
push rod	+	+	—		+(connect)	—
convex ring	—	—	—	+		—
clamping piece	+	+	+ (abrasion)	—	—	

From the matrix, we see that the extension pipe has interactions with other components, but the relationship is not related with the system problem, so we'll not consider the extension pipe at the following process. Finally, a function model of this target patent has been established based on this matrix, which is shown in Fig 4. From the function model, we find out the thinking direction of design around: a. Improve the effects of excessive pushing; b. Eliminate the harmful effects of abrasion.

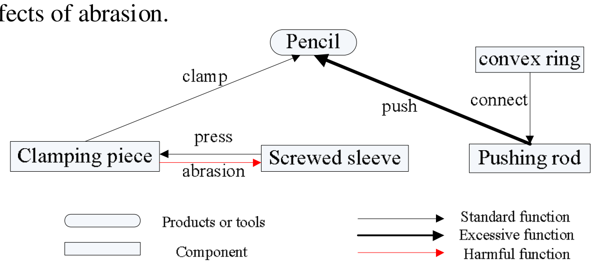

Fig.4. The function model of the pencil extender device

Thirdly, utilize the around strategies and TRIZ problem-solving tools to improve system performance of the pencil extender device. Consider using the around strategies to solve the problem above, a new function model has gotten as shown in Fig.5.

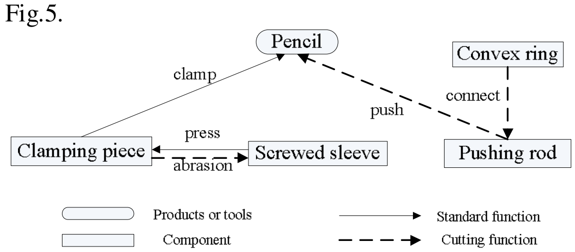

Fig.5. The new function model of the pencil extender device

For problem a, we choose deletion method and try to delete the excessive effect of “push”. According to the table.2, we translate this problem into standard TRIZ problem and use technical conflicts solving method to solve this problem. The improved parameter can be identified as 33-easy of operation, the deteriorated parameter is 32-easy of manufacture. By looking up the contradiction matrix, we find the invention principles are NO.2 Taking out, NO.5 Merging and NO.12 Equipotentiality. The NO.2 Taking out means to extract any features of the product, so as to reduce the complexity and does not affect the whole function of mechanism. According to the inspiration of the principle NO.2, delete pushing rod and convex ring of the original patent, and the exposed pencil length can be adjusted directly by loosening screw sleeve, so there is no necessary to have such function of pushing carried by pushing rod and convex ring.

For problem b, choose substitution method to find out another structure that can substitute the screw-thread fit between screwed sleeve and clamping piece. According to table.2, use the Knowledge-Effect database to solve this problem. By search the database, we find out that the structure of square saw-tooth is better than screw-thread fit, which can overcome the wear and tear resulted from screw-thread fit.

The last step is to refine and optimize the design concept above and conduct infringement judgment for the new product. Finally, a totally different new product has been gotten. It mainly includes two structures, which are extension pipe and tighten set. The tighten set is placed in the middle part of the extension pipe, which can be moved up and down to clamp the clamping piece. With this structure, the loss of tighten set which may cause by user's careless can be avoided. Delete pushing rod, pencil can be pushed directly from the clamping piece. Furthermore, adopt the square saw-tooth mating between tighten set and clamping piece, which can effectively improve the convenience of the system and extend the life of the product. Finally, a new product that avoided the original patent has came out, as shown in fig. 6.

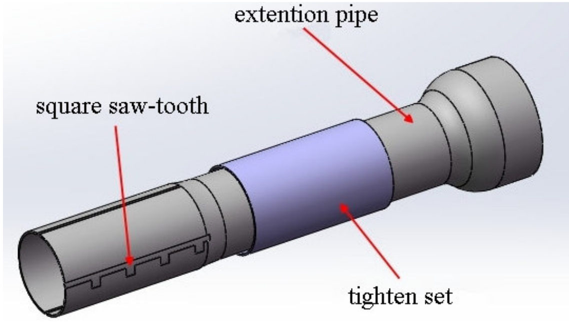

Fig.6. The new product of the pencil extender device

4. Conclusion and discussion

The paper combined the function analysis and TRIZ problem-solving tools with patent design around to develop a new product. The function analysis could help designers understand the target patent more deeply, dig out core technologies and defects of the target patent. Meanwhile, gathering around strategies and TIRZ problem-solving tools together could help technicians for choosing innovative approaches more effectively, and improve application of TRIZ in the enterprises. A case study of a pencil device is applied in this paper to verify the method, and finally a new product which is not infringe the existing patent has gotten. This method has practical significance and guidance for enterprises and designers.

Acknowledgements

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TRIZ Future Conference 2014

Innovation of Coordinate Measuring Machine Using TRIZ Methodology

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Abstract

The paper is focused on the innovation of a stand for a portable Coordinate Measuring Machine (CMM), which is used for measurement and dimensional analysis of automobile bodies in the company Skoda Auto, a.s., Czech Republic. The main aim of innovation was to reduce the time of measurement and increase the productivity of the measurement process and data analyses. The paper describes the method of solving technical contradiction with the use of the TRIZ methodology. Altshuller's table of 40 principles for solving technical contradiction and a super-system were used. Solving the contradiction significant simplified the drive and control elements of the CMM stand. The paper shows the design process of the CMM stand from the stage of concept generation to the stage of the final CAD model, which will be used for the production of the CMM stand. The selection process of the best concept, solving of technical contradiction using TRIZ, the 3D CAD model created in the software Catia V5, the results of strength analysis computed using the finite element method (FEM) in the software Ansys are introduced as well. This innovation simplifies the CMM stand, reduces the time of measurement and increases the productivity of the measurement process and data analyses. The paper introduces a practical example of the use of TRIZ tools in a real industrial environment. The innovative product is currently ready for production in the company Skoda Auto, a.s., Czech Republic.

Keywords: TRIZ, technical contradiction, productivity, CMM, measurement.

1. Introduction

These days, in nearly every industry there are increasing demands on improving the quality of products and a targeted reduction of energy consumption in the overall production process. Therefore, there have been significant changes over recent years in the measurement of individual components and in the field of precise dimensional analysis. The trend is moving away from the contact point sensing of data towards contactless sensing, where the measurement is based on the principle of optical elements [1, 2]. This is a method of sensing, which is based on the collection of data by scanning with a laser beam in the visible range with a wavelength of $\lambda \sim 633 \pm 33$ nm, or invisible, infrared parts of the spectrum with a wavelength greater than $\lambda \sim 760 \pm 51$ nm. More accurate methods of measurement used to capture data include a combination of 3D Full HD digital cameras and multi-sensors or measurements using photogrammetric methods [3-6]. The benefit of introducing new technologies to the field of precision measurement and data analysis is the reduction in cost of touch screen CMM (Coordinate Measuring Machine) equipment. In order to optimize production processes and the downsizing that occurs in industry CMM equipment is used to perform control measurements in order to stabilize the quality of products in large batch production. Reducing the cost of touch screen CMM equipment makes precise measurement technology more accessible to a wider range of customers. The Infinite Arm CMM equipment (Fig. 1) from the company Romer is a portable six-axis machine, which is used in the company Škoda Auto, a.s. The Infinite Arm CMM equipment is used to perform rapid analyses during the development phase of vehicles (pre-production automobiles), to check the dimension of batch automobiles and the need to analyse data from customer automobiles (servicing). The spatial accuracy is ± 0.051 mm, and the point repeatability is ± 0.038 mm. The structure is made from a non-homogeneous carbon fibre composite. The advantages of using composite materials over other isotropic materials include their low thermal expansion, low weight and high strength [7-10]. Therefore, a portable CMM arm does not require an environment with a constant temperature, as gantry CMM equipment does. The measurements are provided by accurate incremental rotary encoders from the company Heidenhain. The low mass of the CMM arm is an advantage during manipulation and the equipment is supported by two-way wireless communication between the measuring arm and an evaluation PC via microwave data transmission.

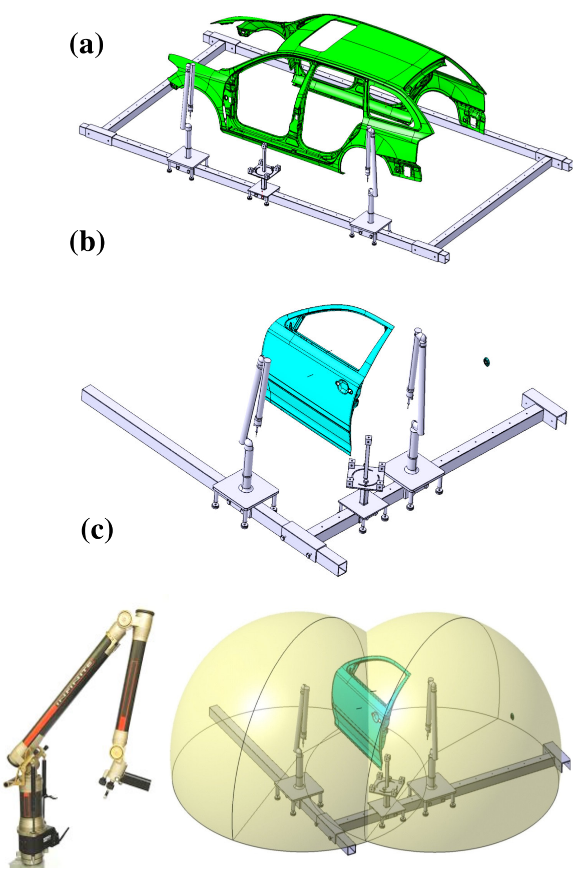

Fig. 1. (a) Assembly of the measurement platform for measuring the body; (b) Assembly of the measurement platform for measuring the side doors of the vehicle; (c) Visualization of transferring the coordinate system during the measurement of the side door of the vehicle.

The problem is to find innovative and cheaper alternatives to electrically operated actuators and the production of complex and costly mechanisms of the Infinite Arm CMM equipment. In this article we used the TRIZ method to find innovative solutions, in order to maintain the desired properties of the CMM measurement equipment for application in the automotive industry.

2. Materials and methods

2.1. Basic requirements for the product

The main requirement for the product was to ensure maximum dimensional stability, which is a necessary condition to avoid the introduction of measurement errors due to deformation of the product. Accuracy of the CMM is defined by the standard ISO 1030360, as measurement uncertainty with the maximum permissible error of measurement MPEE. This error must then be added to dimensional errors caused by external influences such as vibration, temperature variations, and random cantilever forces generated during the measurement process. In terms of stability, the product should have a particular base with a sufficiently rigid structure to withstand external forces in order to prevent distortions affecting the accuracy of the measuring system. Resistance to atmospheric conditions and compensation for expansion due to changes in ambient temperatures should be considered when choosing the material of the product. Secondary requirements for the product result from the needs of the CMM operator and are:

- mobility,
- height displacement,
- multifunctionality
- user-friendliness,
- increased measurement capacity.

The final component of the structure solution was sought in two steps. First the concept was created without the use of TRIZ. Subsequently, the initial design solution was optimized using TRIZ.

2.2. Primary design of the structure of the product without the use of TRIZ

In order to ensure stability and static certainty of the product a structure was chosen with three stabilizing supports, an electrical drive using a set of stepper motors labelled QSH6018-65-28-210 controlled by a microprocessor unit. Height displacement in the Z axis was solved using the screw positioning device HT05/HR05 from the company MecVel. The advantage of this solution (Fig. 2) is continuous, precise control and high manoeuvrability. The disadvantage is the complexity of the system.
In view of the above requirements, structural steel was chosen for the structure having a density of ρ=7860kg.m^{-}

^{3}, thermal expansion coefficient of $\beta=12x10^{-6}K^{-1}$ and Young's modulus of $E=2.1x10^5 MPa$. We also considered composites filled with fibreglass, aramid or carbon fibres which have low thermal expansion, high strength, and a high Young's modulus (carbon $E=3.85\ x10^5 MPa$, Kevlar $E=1.2x10^5 MPa$). However, they were discarded due to their high acquisition cost and complexity of processing technology.

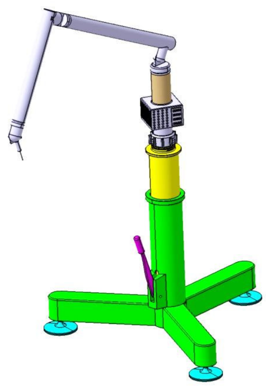

Fig. 2. The initial design without the use of TRIZ

After creating a 3D concept in CAD finite element analysis was performed (Fig. 3) in the Ansys program, which is used for solving simulation problems of implicit algorithms. The implicit algorithm defined by equation (1) is better for such a task than the explicit algorithm mentioned in [11-14].

$$\delta u_{i+1} = u_{i+1}^{t+\Delta t} - u_i^{t+\Delta t} \qquad (1)$$

Where $u_i^{t+\Delta t}$ is vector of nodal displacements for ith iteration in the time $t+\Delta t$.

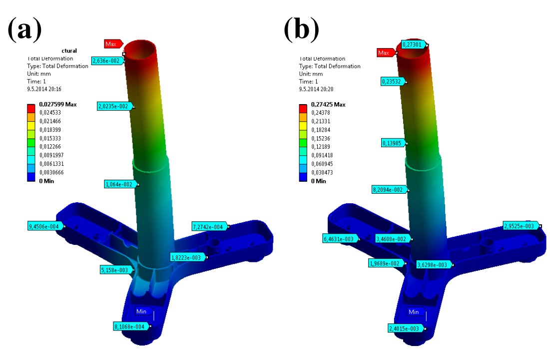

Fig. 3. (a) FEM analysis - maximum deformation during the measurement (b) FEM analysis - maximum deformation during manipulation

The simulation was performed for two onerous conditions, for the state during measurement (fig. 3a) and for the state during manipulation with the CMM (Fig. 3b).

The simulations determined that the maximum deformation of the product during the measurement may reach values of 0.0263 mm, which is acceptable for the required purpose of the measurement. During manipulation the load force is much higher, for this condition the maximum stress was determined for the critical point of the structure; this stress has a value of only 25 MPa. Damage to the product during manipulation cannot be assumed.

2.3. Secondary design of the structure of the product with the use of TRIZ

Primary design of the structure of the product designed without the use of TRIZ had some weaknesses. The complexity of the desing is the main weakness. Model of technical system of primary design is shown in the figure 4a. The aim was to find a simplified design that ensures stability of CMM during measurement and also ensures easy displacement of CMM with a minimum of operator´s effort. The TRIZ methodology [15], which is used to solve various innovative tasks [16-18], specifically Altshuller´s matrix of 40 inventive principles for technical contradiction solving [19] were used for simplification of the primary design and ensuring required functions. When applying this matrix it is necessary to start with a typical solution, which usually leads to a situation in which one property is improved and another worsened. A typical solution leading to decreased operator´s effort during displacement of CMM is to decrease weight of moving objects (CMM). Parametr **10 - Force** is improved, but parameter **1 - Weight of mobile object** is getting worse from the viewpoint of the stability of the CMM. From Altshuller´s matrix of 40 inventive principles for technical contradiction solving is apparent, some of the principles 1 – Segmentation, 37 – Thermal Expansion, 18 – Mechanical Vibrations, 8 – Counterweight could be used for this technical contradiction solving. The source and distribution of compressed air is in the supersystem. Using the source of compressed air from supersystem and **principle 8 - Counterweight**, which says:

- place your object into environment that provides aerodynamic, hydrodynamic or other lifting force,

- compensate for the weight of your object with merging it with another object that provides lifting force,

the technical contradiction can be solved.

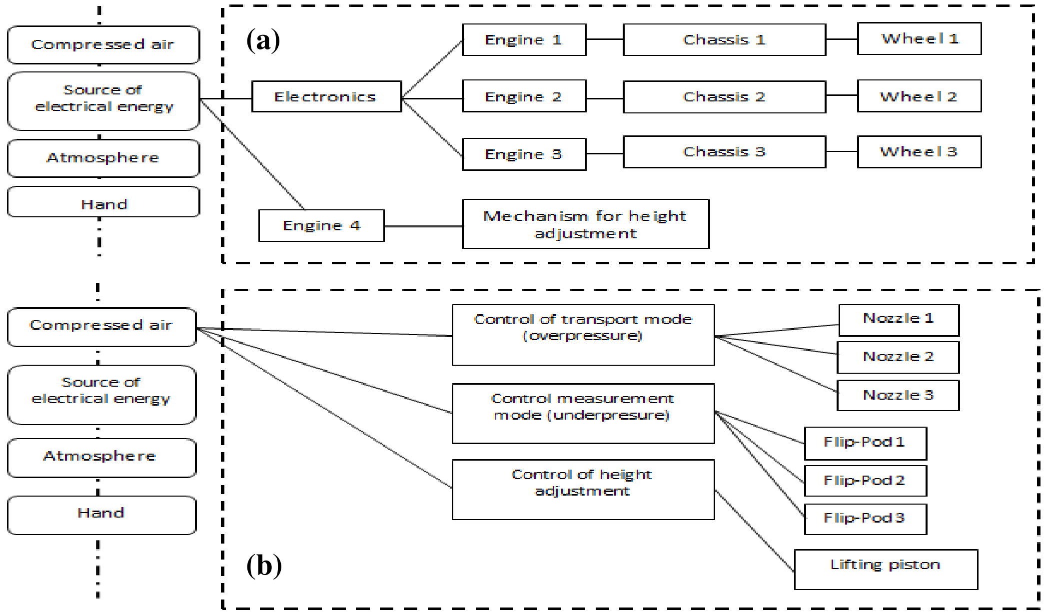

Fig. 4. (a) Model of technical system of primary design before the use of TRIZ; (b) Model of technical system of secondary design after the use of TRIZ.

2.4. Describtion of secondary design

The resulting technical solution (Fig. 5) uses a nozzle (bag) to lift the product during manipulation and suckers (Flip-Pods) to ensure the stability of the product during the measurement. The model of the technical system of the innovative product after the application of TRIZ is shown in Fig. 4b. During the final design we approached the producer Horst-Witte, which specialises in pneumatic systems, who offered a possible solution. The company Festo helped with the design of the pneumatic system (Fig. 6) with the help of the Fluid Sym 5 program.

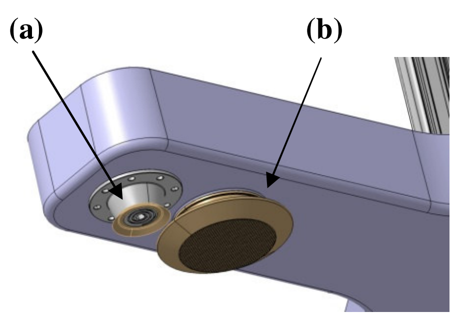

Fig. 5. Close up of the technical solution of the pneumatic system: (a) Flip-Pod - stabilization of the measurement with a vacuum pump; (b) Transport air bag with micro-holes

During the measurement the measuring device stands on three points which stabilize it. If the measuring device needs to be moved the pneumatic equipment is activated which picks up the measuring device, which can then be moved by the operator to the next measurement position with minimal effort. This equipment is a bag (Fig. 5b) with micro-holes in the bottom part which rests on the floor. Compressed air forms enough buoyancy on the surface of the bag to lift the product. The air escaping from the micro-holes creates a boundary layer separating the surface of the transport bag from the floor, thereby reducing the friction between the bag and the pad to a minimum and allowing the operator to manipulate with the device. The advantage of this innovative solution is the removal of all mechanical and electronic elements from inside the measuring device. The pneumatic system is supplied by a central distribution of compressed air with a guaranteed pressure of 0.6 MPa for a consumption of approximately 150 l/min. Pressure losses in the pipes, the influence of pipe roughness and leaks are negligible (Fig. 7) due to the overall length of the installation <10 m and the internal diameter of the compressed air pipe for the transport bag and vacuum ejector from the company Festo VN-20-L-T6-PQ4-VQ5-RO2.

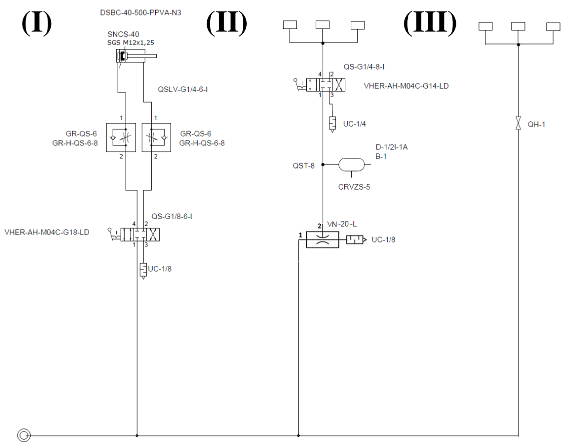

Fig. 6. Diagram of the design of the pneumatic system of the product for measurement with CMM equipment: I – Elevation, II – Flip-Pods control, III – Ejectors

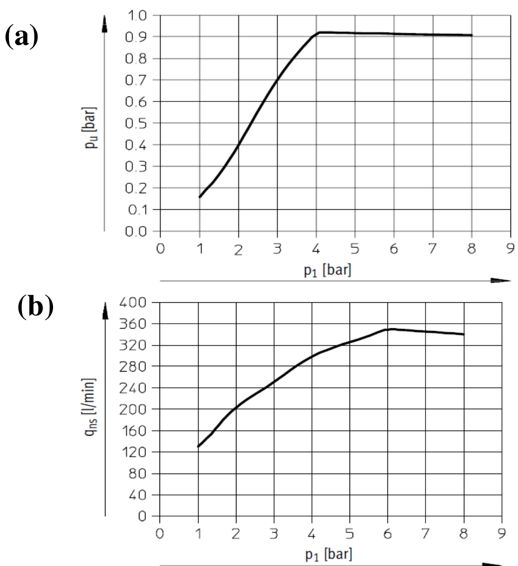

Fig. 7. (a) Vacuum pu as a function of working pressure p1; (b) volume suction rate qn as a function of operating pressure p1

The second component of the resulting solution is the implementation of the Flip- Pod (Fig. 5a), which along with the vacuum ejector VN-20-L-T6-PQ4-VQ5-RO2 creates a vacuum of approximately 0.09 MPa between the flat Flip-Pod and the floor, thereby increasing the downward force during the measurements where it is necessary to stabilize the device. The amount of downward force depends on the material the rubber seal is made from, the roughness of the underlay and the degree of sealing between them. The total downward force is then the resultant forces composed of the normal force and the forces induced by the vacuum ejector. The intention is to eliminate the possibility of the device slipping sideways and reducing the accuracy of the measurement. By using the elements of the supersystem (compressed air) the mechanism for height adjustment of the measuring device was removed – this was replaced by the pneumatic actuator, driven by the compressed air. After performing the installation of the pneumatic components the final concept of an innovative product for the CMM equipment was created (Fig. 8).

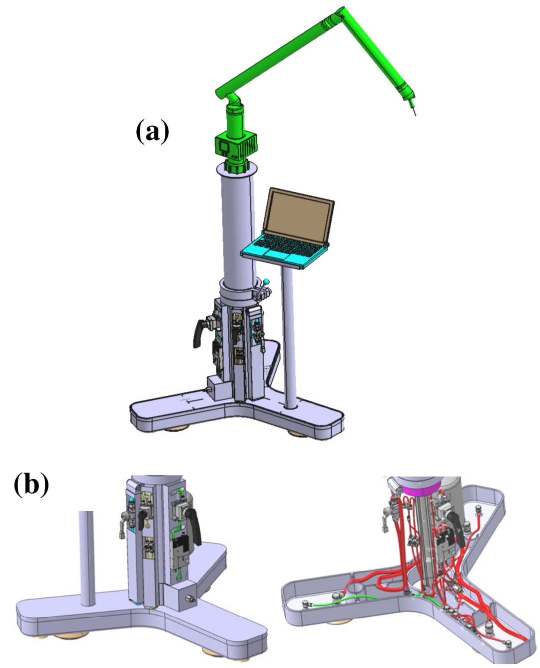

Fig. 8. (a) The final form of the product for measurement with the CMM equipment, (b) detail of the pneumatic system

3. Results

The product of the CMM was innovated by the application of the TRIZ method. The innovation brought the following:

- removal of wheels of the mobile, electronic and mechanical elements and their replacement with a pneumatic system,
- removal of the mechanism for height adjustment and its replacement with the pneumatic actuator with mechanical arrestment,
- elimination of possible horizontal displacement of the measuring device by the use of a pneumatic system with Flip-pods,
- reduction in the cost of production by 43%,
- reduction in the preparation time and an increase in the measurement range of the CMM equipment, which allows an increase in the capacity of the dimensional and data analyses by 25%,
- reduction in labour intensity of the analyzes and savings on one operator of the measuring device

- by reducing the time for performing the analysis, increasing the capacity of the measurements and making savings on the operator we recorded an annual increase in profit of approximately 48%.

4. Conclusion

The original structure of the CMM was replaced with an innovative CMM structure. The TRIZ method played a major role in finding an innovative solution, as it provided a substantial simplification in the structure whilst maintaining the required features and functions of the CMM. One of the main points of the solution was the use of the compressed air distribution, which is part of the supersystem. This was used as a source of pressure for the bags which lift the CMM and thereby facilitating manipulation of the CMM and also the source of vacuum for the Flip-pods, which ensure stability during measurement. The innovative technical solution of the CMM increases productivity of the measurement process which leads to a profit increase of 48%.

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Parameters and Contradictions in Indoor Accessibility Problems

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Abstract

The nature of problems in architectural design is connected with spatial, technological, social and aesthetic matters. Citizens` rights to equal opportunities of access and use the public space is one of the most challenging spatial problems in architectural design. Accessibility problems have various parameters that raise contradictions. The aim of this study is exploring the parameters and contradictions raised by accessibility indoor problems, through the analysis of a small inventive problem in architecture: improving the accessibility spatial conditions in a university environment. We considered three aspects of problem including accessibility measuring, integration and way finding. In conclusion some parameters are more applicable from other parameters in this type of problems. Meanwhile in some cases, spatial problems have non-spatial solutions. This causes difficulty for testing the solutions by double measuring of integration.

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Keywords: Contradiction; architectural design;TRIZ; design parameters; spatial accessibility; wayfinding; indoor accessibility

1. Introduction

Designers play a central role in ensuring of the accessibility conditions of the built environment. Far behind the legislation, the designer is the most direct interpret of the clients/users' needs and the person who is able to find innovative answers and conform the environment on a suitable way to them. The importance of the question has only been recognized, at the end of the last century, in the form of accessibility legislation and official recommendations which aims the defense of citizens` rights to equal opportunities of access and use the public space [1, 2]. However, since it is a new field to explore, designers need appropriate methods and appropriate tools to face the complexity of the questions raised by the inclusive design approach [3].

Solving these problems raises contradictions. In this paper we address contradictions of spatial problem in architectural design considering accessibility and spatial integration, a measure that allows to quantity accessibility, and preview the distribution of the movement flows in probabilistic terms, in spatial systems [4].

The accessibility term is also been widely used in the area of transportation-planning [5]. According to Chen [6] accessibility is essential for evaluating the interrelationships between land use patterns and the systems nature of transportation . Several scholars have studied accessibility focusing different points of view, Such as location accessibility individual accessibility or economic benefits of accessibility [7]. Accessibility has been discussed in urban scale (outdoor) and indoor buildings. In TRIZ theory this can be considered as accessibility in super-system, system and sub-system. Vanclooster [8] argues that spatial accessibility problems should be adapted to the complexities of indoor environment. The author mentions two main differences between indoor and outdoor environment. First, outdoor environment is considered not to be so constrained by built infrastructures as indoor environment; second, way-finding in multi-level buildings are more difficult than outdoor environments due to floor levels, staircase and visual limitations [9].

According to Rantanen [10] appropriate accessibility in buildings must be considered as an ideal final result in buildings design. Rantanen believes that the concepts, tools and principles of TRIZ can be used to increase accessibility. He also argues that “accessibility recommendations” according “universal design” and “design for all” [11] perspectives will have a wider and easier application, recurring to the TRIZ 40 principles. Kiatake [12] has applied TRIZ to solve an accessibility problem for disabled people. She has used ISQ innovation situation questionnaire for formulation of problem. From the 39 engineering parameters of contradiction matrix, the author applied the parameters 36 (complexity of device) and 13(stability of composition), the principles 2, 35, 22 and 26 (extraction, transformation of properties, convert harm into benefit, copying) can be applied in intersection of principles 36 and 13.

We argue that the number of contradictions, in accessibility problems, is higher than what previous researchers have been addressed. The aim of this study is to deep the formulation of contradictions in current accessibility problems in indoor environments. Accessibility will be evaluated by the point of view of integration value proposed by Space Syntax theory [4].

2. Accessibility problems in buildings

One definition of accessibility (U.S. Department of Environment, 1996) is ‘‘the ease and convenience of access to spatially distributed opportunities with a choice of travel’’. ‘‘ease and convenience ’’which is particularly complex as it is a function of varying types of trips and activities and most likely varies a cross people according to their tastes and preferences [5].

Accessibility can be related with the degree as a way finding task and be processed in an environment in the easiest way, especially for those who are unfamiliar with that environment [13]. The costs of poor accessibility conditions and uneasy way finding can be multiple and serious (e.g. frustration and anger, loss of time, loss of opportunities, being late for appointments, risk of life). In spite of such costs, way finding processes are still roughly understood [14].

Passini [15] regards way finding as spatial problem solving and on this basis develops his “Way finding Design” framework. Weisman [16] considers that the floor plan configuration is the most influential one on way finding performance. Space Syntax [4] has introduced formalized, graph based accounts of layout configurations into architectural analysis. Calculations based on these representations express the connective structure of rooms and circulation areas in a building. Those topological relations are described in terms of a set of layout configurations measures considering the relative position of a node into the global graph. The most considered one is integration, a global measure that describes the average depth of a space to all other spaces in the system. The syntactic depth between two spaces is the least number of nodes in a graph that are needed to reach one from the other The spaces of a system can be ranked from the most integrated to the most segregated [17]. The more integrated a space is, the more accessible.

Peponis et al [18] showed that there is a relationship between the level of integration of a given place and the relative use of that space during observed way finding tasks. Highly integrated places within a building were more likely to lie along paths chosen by people during a search. The more integrated paths are also the more accessible ones i.e. the closets paths to all the others or, in other words, the easiest to reach or the more central ones in the spatial system. According Dogu et al [19] the circulation space is the key organizing force of a layout since it is the space in which people move, in which they have to make their way finding decisions, and in which they have to find their way. Thus, it is the spatial accessibility issue that we try to understand in this paper following the TRIZ approach.

3. Modelling accessibility and integration problems by TRIZ

3.1. Statement of Problem

For formulation of problem we used F-1 and F-2 forms by Altshuller [20]. Form F-1 helps the formulation of a characteristic to be improved and involve the name, goal, operation and main elements of technical system and their functions in order to determine the characteristics that should be improved or eliminated. Form F-2 helps the formulation of technical contradiction that involves the characteristic, conventional means to improve the characteristic and characteristic that is getting worse under improving first characteristics.

Considered problem in this study is less integration i.e. segregation in the building system of the IT computer laboratory of DECivil (the Department of Civil Engineering, Architecture and Georesourses) of Instituto Superior Técnico, localized in floor 1, and, consequently, the uneasy accessibility of this space for unfamiliar users. DECivil building is a 6-storey building with 3 floors above ground. It has several facilities that attract daily the academic population of the campus (e.g. bar, canteen, students working spaces). Ground floor, floors 1 and -1 are the most used by students. Besides facilities, those floors have also classrooms, auditoriums and specialized labs. Floors 2 and 3 are occupied, mainly, by professors’ cabinets. The IT space lab consists of internet connected computers that professional software has been installed for students. Although there is print and plot service part inside space that students can send files for print from each computer. The lab is located at first floor, at the northern end of the eastern corridor (see Fig. 1 and Fig. 2) and is accessible by three stairs and elevators (southern, middle and northern). The location of lab makes acoustic comfort for students during working and also benefits from good natural light from three sides. In contrary, the integration and accessibility of lab is very low. Meanwhile way finding for newcomers is a challenge. The characteristics that should be improved are accessibility and integration (integration of a space can be calculated by Depthmap® software [21]). The improvement of the integration of a space (e.g. relocating the lab in the system, changing the system layout) will improve the accessibility to that space.

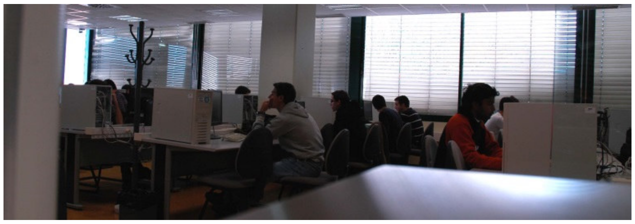

Fig. 1. A view from Computer Lab in Decivil.

Central in the system it is i.e. the more accessible that space is from/to every other spaces of the system. Conventional means to improve the characteristics of accessibility, integration and way finding

- Integration: changing the location to the middle of building (is not feasible) also deteriorate the natural light and acoustic comfort. Another way is creating another direct entrance to outdoor that decrease controllability of space.

- Accessibility measuring: shortening the path from entrance of building to computer lab can assume as easy accessibility.

- Way finding: way finding refers to the techniques used by travelers over land and sea to find relatively unmarked and often mislabeled routes. Way finding has been used in the context of architecture to refer to the user experience of orientation and choosing a path within the built environment. Applying a lot of signs for easy way finding may increase the complexity of space.

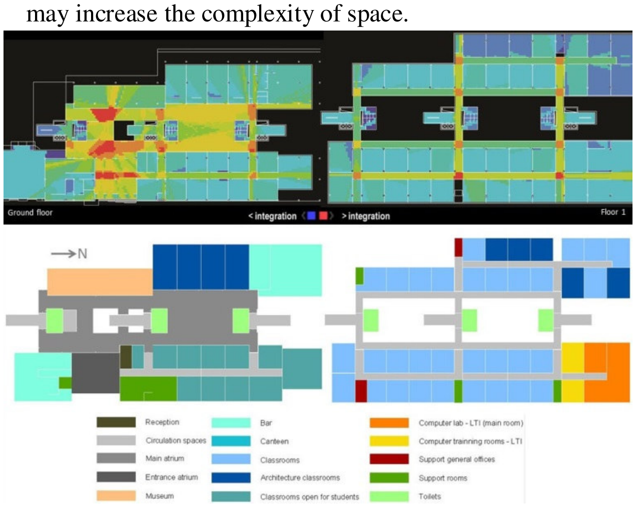

Fig. 2. Ground floor and floor 1 of DECivil building: VGA (Visibility graph analysis) by Depthmap® software (top); plans (down). The IT computer lab is specified by orange.

The Fig.1 shows the visibility graphs (VG) of ground floor and floor 1 of DECivil, produced by the spatial analysis software of DephtMap® [21] showing the distribution spatial integration values. VG is a syntactic representation based on the division of a floor plan, according to a grid, and linking each grid cell to all the others cells "visible" from that cell. Although each grid cell has an integration value associated, the graph scale color allows an immediate interpretation of how visual integration is spread in the spatial system [22]. The VGs shows that the computer lab is located in a less integrated zone in the building system.

Table 1. Name, goal and requested improved characteristics in TS (technical system).

Name of the TS	The goal of the TS	Characteristics that should be improved
Computer Lab	Software, internet, print, project team work	Integration, accessibility, way finding

In architectural buildings as technical systems, users are inside system and consequently are part of systems. Users can be assumed as moving or mobile objects of system. According to formulation of problems, parameters 4 (length of stationary object), 15 (time of action of moving object), 19 (energy spent by a moving object), 24 (loss of information), 25 (loss of time), 33 (convenience of use) 36 (complexity of a device), 37 (complexity of control) 38 (level of automation), 18 (brightness) can be considered. The parameters will be described by accessibility terminology.

- Parameter 4: length of stationary object is the length of path from beginning to destination by user (a moving object)
- Parameter 15: Time of action of moving object is the time that user can recognize and respond to the environment to better accessibility. In fact this parameter is related to way finding by user.
- Parameter 18: Brightness can be translated to natural or artificial lights in spaces.
- Parameter 19: Energy spent by a moving object is the energy that is spent by user for getting access to space. Spent energy by user is correlated by length of path and intelligibility and integration of space.
- Parameter 24: in accessibility problems, Loss of information is related to the existed information by space that can lead the user to destination.
- Parameter 25: less accessibility of spaces can cause loss of time for users.
- Parameter 33: increasing accessibility in a building prepare more convenience of use by user.
- Parameter 36: less accessibility increases the complexity of a device (building).
- Parameter 37: one example for complexity of control of spaces is when we have more than one entrance for spaces. Also control is one of parameters in space syntax theory.
- Parameter 38: increasing level of automation for way finding signs can increase the complexity of building.

Cavallucci [23] has discussed about contradiction clouds. He tried to present a mathematical model for contradictions. In his opinion, in the complex design problems, the high amounts of contradictions are connected to each other. In the first stage he models the contradiction as below: (Table 2).

"An Active Parameter (AP_x) having two states of values diametrically opposed (V_a and $V_{\bar{a}}$) influencing respectively two evaluating parameters (EP_n and EP_m). The state of contradiction is obtained since the opposite state ($V_a \rightarrow EP_m$ and $V_{\bar{a}} \rightarrow EP_n$) is also true.

Table 2. Active and evaluating parameters in accessibility problems.

TCn,m	Active parameter (Parameter 4, length of stationary object)	
	Va(long)	Va(short)
EP1- Parameter 18: Brightness	☺	☹
EP2- Parameter 15: Time of action	☹	☺
EP3-Parameter 19: Energy spent by a moving object	☹	☺
EP4-Parameter 25 Loss of time	☹	☺
EP5- Parameter 33- convenience of use	☹	☺

Table 2 shows active and evaluating parameters of accessibility measuring in our problem. Parameter 4, length of stationary object (path) is assumed as AP and parameters 15,18,19,25 and 33 are EPs. This table can be created by other AP and EP for accessibility measuring aspect of problem. Also there are other AP and EP for way finding and integration aspects of problems.

Each aspects – accessibility, integration and way finding – deals with different parameters and contradiction. For example in accessibility aspect, the main worsening parameter is parameter 4 (length of stationary object).

3.2. Using contradiction matrix and 40 principles

Table 3 shows the picked up contradiction matrix for effective parameters in all three aspects of indoor accessibility problems.

According to contradiction table, for solving contradictions between parameters 4, 18, principles number 3(local quality), 25 (self-service) can be used. In intersection of parameters 4 with parameters 15 and 19, there are no principles. It means that we can apply all of 40 principles. Parameters 15 and 19 are more related to way finding by user.

Principle 3: Local quality

A. Transition from homogeneous to heterogeneous structure of an object or outside environment(action)
B. Different parts of an object should carry out different functions.
C. Each part of an object should be placed in conditions that are most favorable for its operation.

Principle 25: Self service

A. An object must service itself and carry out supplementary and repair operations
B. Make use of waste material and energy

By using a combination of above mentioned principles we can suggest some solutions. By using self-service principle, we can suggest self- service printers in social space of Decivil in which computers can connect wirelessly to printers, many of students use lab only for printing, and they can connect to wireless self-service printers by their laptops. These kind of

Table 3. Contradiction matrix for effective parameters in accessibility problems.

parameters	4	15	18	19	24	25	33	36	37	38
4			3,25		24,26	30,29,14	2,25	1,26	26	
15			2,19,4,35	28,6,35,18	10	20,10,28,18	12,27	10,429,15	19,29,39,35	6,10
18		2,19,6		32,1,19	1,6	19,1,26,17	28,26,19	6,32,13	32,15	2,26,10
19		28,35,6,18	2,15,19			35,38,19,18	19,35	2,29,27,28	35,38	32,2
24	26	10	19			24,2628,32	27,22		35,33	35
25	30,24,14,5	20,10,28,18	1,19,26,17	35,38,19,18	24,26,28,32		4,28,10,34	6,29	18,28,32,10	24,28,35,30
33		29,3,8,25	13,17,1,24	1,13	4,10,27,22	4,28,10,34	12,26,1,32	32,26,12,17		1,34,12,3
36	26	10,4,28,15	24,17,13	27,2,29,28		6,29	27,9,26,24		15,10,37,28	15,1,24
37	26	19,29,39,25	2,24,26	35,38	35,33,27,22	18,28,32,9	2,5	15,10,37,28		34,21
38	23	6,9	8,32,13	2,32,13	35,33	24,28,35,30	1,12,34,3	15,24,10	34,27,25	

Printers occupy very less space in social space in middle of Decivil. This solution also can be confirmed the part C of principle 3.

4. Modelling problem by Su-Field

The core idea of Su-Field is that every problem can be formulated in its simplest form as an interaction between S2 and S1 via field. In other words Su-Field model is the second method for solving contradictions. Instead of opposing parameters (solved by contradiction matrix), in this method opposing actions are solved by 76 standards [24].

Altshuller [25] created the law of increase of Su-Field. According to this law all technical systems tend to increase the degree of Su-Field. The law states that non Su-Field systems are going to be promoted to Su-Field systems. Also Su-Field systems tend to transition from mechanical to electromagnetic fields, enhance the fragmentation degree and the number of elements connections. Altshuller [26] has explained the mechanism of enhance of Su-Field. Non Su-Field systems tend to become a simple Su-Field "then to complex Su-Field (internal, external, and based on environment and modified substance of environment), then towards chain Su-Field, double Su-Field and forced Su-Field."

The most effective interactions in spatial problems are interactions between user and space also space with other spaces. Space Syntax theory considers the interactions of spaces with each other and way finding and accessibility issues are related to user-space interactions. For modelling our indoor accessibility problem by Su-Field, we choose computer lab and users of space as S1 and S2 (See fig. 3). Also other considerable substances for problem are computer lab and main lobby of DEcivil. The field can be stated as: the computer lab informs user. We can have different types of fields in Su-Field modelling, e.g., useful, harmful, absent, ineffective, excessive and measurement/detecting. In the Su-Field modelling of our problem, the fields are ineffective in both cases: interaction between user and computer lab and interaction between computer lab and main lobby. We use inventive standards flowcharts [24] to recognize which standards are applicable. Standards of class 1 (improving the system with no or little change) and class 2 (improving the system by changing the system) are applicable.

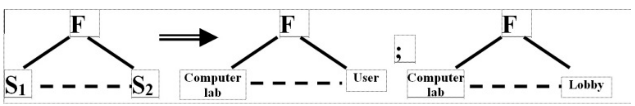

Fig. 3. Su-Field model of problem.

5. Modelling problem by nine windows technique

Ability to define a problem clearly is one of the most common roadblocks to solve it innovatively. One of the main causes to this condition is the complexness of real situations [4]. Nine windows technique offers a holistic view of a problem by using past, present and future of sub-system, system and super system. It can be a good step to a clear problem definition. By using this method one should answer this question: can we do something at the sub-system, system, and super-system level in advance, in present, in future to fix the problem or improve the system? Fig. 4 represents the nine windows technique for the problem of accessibility to computer lab.

Three main function of computer lab in this problem is using software in computers, using internet and printing documents. Personal laptops and wireless internet can make useless the first two functions. The third function by paperless movements is going to disappear. In case that we need printing, the portable onboard printers on laptops in future may be a solution. These kinds of printers consume powder or compressed material to produce paper and print. Also these devices may be used to recycle the printed paper to the same compressed material.

6. Conclusion

The purpose of this study was recognition of parameters, actions and contradictions for solving indoor accessibility

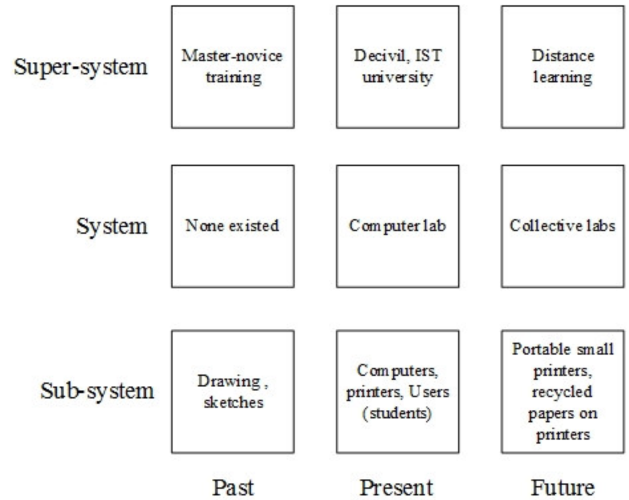

Fig. 4. Nine windows model of problem.

problems. The costs of uneasy way finding and poor accessibility are high. Finding and formalization of contradiction is a key step for understanding and solving accessibility problems in an innovative way. Indoor accessibility problems involve 3 aspects - accessibility measuring, way finding and integration - that have mutual effects on each other. Solving each aspects and found solution may help another aspect. Some parameters of contradiction matrix are more applicable than others. Meanwhile, in some contradictions we can apply all principles. This shows the variety of solutions that can be considered in accessibility problems.

In beginning of research the assumption was that by finding solution for integration of space and modifying of that, we can measure again integration of space for testing the solution reliability. We concluded that in some cases this method is not applicable, because this type of testing is applicable when we change the infrastructure materials of space, while inventive solution of problem may different as the proposed solution is. This means that sometimes architectural spatial problems have non spatial solutions.

We also made Su-Field model for problem. Considering importance of user-space and space-space interactions, the substances were chosen computer lab, user and main lobby. According to different type of fields, the field in this problem was recognized as insufficient and standards class 1 and 2 were proposed to use. Nine windows modelling of problem showed that technology development has created new needs for special spaces such as computer labs. Also development of technology in future may cause to lose the need for these kinds of spaces.

For future studies solving indoor and outdoor accessibility problems by Su-Field (testing the increase of degree of Su-Field) and also creating a bridge between outdoor and indoor problems by concepts of 9 windows is proposed. Also using 4*4 windows for connecting the accessibility problems of computer lab, DECivil building, university campus and Lisbon city is proposed.

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

Trend of S-curve evolution for roadmap development in the lighting industry

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Abstract

The lighting industry is going through a major transformation initiated by the technological breakthrough of Light Emitting Diodes (LED). Since 2008 all major traditional professional lighting companies have been transforming their portfolio of products into LED based lamps and fittings. With the help of the TRIZ S-curve evolution methodology strategic choices could be made resulting in a sustainable conversion from traditional incandescent and gas discharge based lighting to LED based lighting solutions. The method of S-curve evolution offers clear guidelines for interdisciplinary teams consisting of marketing, application, product design and research & development. The talk will illustrate and analyze these using a variety of examples from the lighting industry. Results of this process include a well-balanced product roadmap, active product lifecycle management and sound business figures of newly introduced products.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: TRIZ, S-curve, Trend of evolution, Lighting, Roadmap

1. Introduction

This paper describes the use of the TRIZ S-curve and the trends of evolution in the lighting industry. Today the lighting industry has arrived in a phase of conversion as conventional lighting is gradually replaced by lighting based on Light Emitting Diodes (LEDs). These shifts from one S-curve to another are obvious in the lighting industry: from moonlight to open fires to candles, from candles to gas-energized lighting. And further along the road to electrical lighting. The next conversion realized is from electrical lighting based on incandescent lamps to lighting based on gas-discharge light sources, and from stand-alone light-giving elements towards systems. Not only in light generation the S-curve methodology has been applied, however, also in the application of lighting.

This paper gives examples both of the analysis of existing lighting systems as well as the pro-active use of S-curves for product programming and market introduction of new products. Successful and less-successful examples are given and analyzed.

1.1. Lighting industry making a conversion

The lighting industry has been a stable industry. Before the revolution initiated by the introduction of LED the lighting industry was pretty clear. Few suppliers at the light source side determined the lamps market on global scale for decades. For the electronic control of these lamps, more companies were active, however, mostly on continental scale. The world of luminaire manufacturers has not been consolidated: thousands of enterprises have found a place in the market. Not one single company has a global market share that exceeds 10%, on continental scale market shares are limited to maximum 15%, only on regional scale market share could exceed 30% within a specific application segment, e.g. sports lighting, industrial lighting, office lighting or retail lighting.

Since a few years the lighting industry is going through a major conversion. The availability and quality of Light Emitting Diodes, suitable for general and accent lighting, indoor and outdoor, has changed the playing field, and will further change the playing field. Semi-conductor companies are now supplying the basic light sources (LED die). Drivers of LEDs are still related to those for conventional light sources, also with new entrants at the global market. Traditional luminaire manufacturers face competition from new entrants at the market. The full lighting industry is changing, as it never did before. Companies that will or cannot follow should fear for their future and take firm actions.

1.2. Innovation roadmap programming for functional lighting

How to survive in this changing market field is a key question for a lighting company with a record of more than 120 years? A strong programming for the innovation and marketing roadmap is an essential tool to prepare for the future. It is the combination of anticipating the future and gradually leaving behind the past that will create a healthy enterprise. New products and technologies should be introduced in time. ‘Too early’ results in disappointing sales, ‘too late’ offers new entrants in the market the opportunity to gain market share.

Also the traditional portfolio needs attention. In the 4th phase of the TRIZ S-curve investments are low, tools are amortized already, so the costs go down rapidly, however, still interesting prices can be realized at the market place. A steady phase-out of products, with attention for the golden tail, will result in a bright future for the lighting company on condition that innovations are brought successfully to the market.

The innovation roadmap is a great help to steer the process. Table 1 shows disciplines that typically deal with the innovation roadmap.

Table 1. Disciplines that participate in the innovation roadmap process

Discipline
Product management
Market management
Segment management
Lighting application
Product development
Sales
New technologies
Research and Innovation

All have their specific knowledge and competence and via one common language, the TRIZ methodology, the innovation roadmap can be prepared. Roadmaps are accurate for short term e.g. half a year to one year, less accurate for the mid-term e.g. 3 years, and offer an indication for the longer term.

Picture 1 shows a roadmap overview for the segment ‘Industry’ for the short and mid-term during the transition period in which the conversion from traditional lighting sources towards LEDs was initiated. Both new products and successors of products are present in the innovation roadmap. Timing is crucial; an organization will not run effectively and successfully if all innovations are brought to the market at the same time. The innovation roadmap team determines the priorities and allocates all capacities that are required.

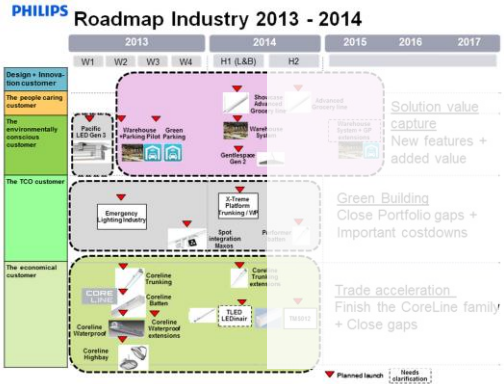

Fig. 1. Overview of a typical innovation roadmap for the segment industry during the transition of conventional lighting towards LED lighting in 2012. (Content partly blurred).

1.3. Light source development – an historical overview

Innovation in the lighting industry is a continuous process. Originally people could only rely on sunlight and moonlight, depending the time of the day, the season and the weather conditions people could benefit from natural light during their activities. Still today in rural areas in Africa and India the only source of light is natural light.

Candles to light up an interior during nighttime were introduced, a real innovation thanks to the clean burning process and the controllability: candles can be switched on and off instantly, in contrast with an open fire.

It was in the 19th century that cities started growing and safety during evening time became an issue. Street lanterns burning gas were introduced. Still today in historical cities we find the traditional lanterns, however converted into electrical operated luminaires. Also households converted their candle lighting into gas-operated lighting, most of the time just at a few spots in the house.

Electrical lighting based on incandescent bulb technology has been the start of many of still existing lighting companies. All over the developed world interior and exterior artificial lighting was introduced, taking away disadvantages of the previous types of lighting. Electrical lighting made that the current systems were phased out on basis of comfort, reliability, safety and efficiency. A new era of light was born. From incandescent lighting to the more efficient and sparkling halogen lighting, and also to gas-discharge lighting (fluorescent tubes and high-intensity light sources).

Also in control of light big steps were realized. Most traditional lighting is diffuse and results in a lambertian light distribution. Technologies like smaller gas-discharge burners, slimmer fluorescent tubes and compact halogen lamps initiated the development of advanced optics. Light directions could be controlled facilitating efficient lighting installations.

With LED lighting, for a few years now the next revolution in artificial lighting has started.

2. Three examples of LED luminaires in the office segment

Three examples are given to demonstrate the power of the TRIZ S-curve evolution laws. Initially the new LED light source could not compete with traditional light sources in view of traditional parameters like efficiency, lumen package, price and performance. Nevertheless the lighting industry was eager to develop and market LED fittings despite of the underperforming champion parameter.

2.1. An early functional luminaire, neglecting the S-curve TRIZ theory.

Approximately in 2008, LED light sources had reached a combination of price level and performance level which allowed the lighting industry to start developing professional luminaires for the mass market. So far only in niche application segments LED had been applied successfully. First the red traffic light, later also the orange and green traffic light. Main driving parameters for traffic lights were efficiency and visibility. The champion parameter was clearly durability and reliability, resulting in virtually no maintenance. The result is visible in all cities: the conversion of traffic lights housing special incandescent lamps towards LED based traffic lights is an example of a very successful conversion in a limited time frame.

Although white LED had been developed, the LEDs could not yet outperform traditional fluorescent lighting. Nevertheless the lighting industry was eager to introduce LED based lighting. A team was initiated and started working on the theme 'Design breakthrough for office lighting'. The end result was a suspended, curved luminaire as displayed in figure 2.

Fig 2. Philips DayWave luminaire (system), the first functional office lighting based on LED technology. A curved luminaire with separated up and down light component, and possibility to set the color appearance, warm-white to cool-white light.

The fact that LED lighting at that time could not equal or outperform traditional fluorescent lighting on the key champion parameter efficiency (lumen/Watt from the system), resulted into the next considerations in the design brief: 'Design should distinguish from a fluorescent luminaire'.

Choices have been made on aspect where the LED luminaire would outperform any fluorescent luminaire e.g.:

- Curved shape, by definition not possible applying fluorescent lamps;
- Step less adjustable white light tone, as shown in Fig. 2;
- Separate switchable and adjustable up light component;
- A touch of colored light, upward (not shown in Fig. 2).

The end result is a very nice, however expensive luminaire. Limited sales were realized. The luminaire has been the iconic product displayed at all marketing materials. However, with this product a real breakthrough in sales did not come.

An analysis by the TRIZ S-curve, and Trends of evolution theory showed interesting conflicts, by which the limited success could be explained.

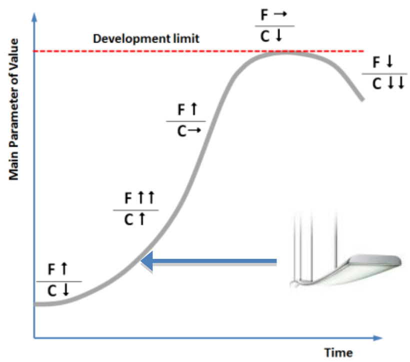

Fig. 3. S-Curve and value increasing chart [1]. The F(untionality) is going up while the C(ost) is reduced, going from the 1st Stage to the 4th Stage. The DayWave was introduced at the start of the Transition Stage.

The suspended curved luminaire is developed at the start of the S-curve Transition stage. Guidelines from TRIZ [2] are clear, however, nobody in the project team was really aware of the rules of TRIZ. Retrospectively the following conflict areas were not taken into account:

- *Recommendation from TRIZ: Adapt components from other engineering systems.*
  Instead a complete new engineering system has been developed. Optics, housing, electronics (including housing) and suspension, all are newly developed.
- *Recommendation from TRIZ: Variety and magnitude of modifications to be foreseen.*
  Big changes should still be possible. Instead a peak-design optical system was developed, not designed to be adapted afterwards, making it costly to upgrade the luminaire with improved technology.
- *Recommendation from TRIZ: Respect super system and physical limits.*
  The super system for fluorescent tubes was a rectangular housing, the super system required for DayWave a customized complicated housing.

- *Recommendation from TRIZ: all parameters must be acceptable, one is superb and the champion parameter.*
  As the default champion parameter in office lighting is application efficiency (lumen/Watt) and traditional fluorescent lamp based luminaires easily outperformed the new LED based luminaire, an alternative was chosen: 'Breakthrough in design'. However, the majority of the potential customers did not recognize this champion parameter.

To summarize: too many functions have been added to this luminaire and the luminaire was never designed for future improvements. As a consequence the cost level could not be reduced, making the luminaire un-attractive for a large number of customers. The luminaire remains an image product with big exposure, however, with limited commercial success.

2.2. A second functional office luminaire, respecting part of the S-curve TRIZ theory.

Fig. 4 shows an application where a second functional office lighting luminaire has been applied. Once again a luminaire with a deviating shape and interesting features and functionality has been developed and introduced to the market. It was during the definition stage of this luminaire that the S-curve methodology was implemented in a late phase.

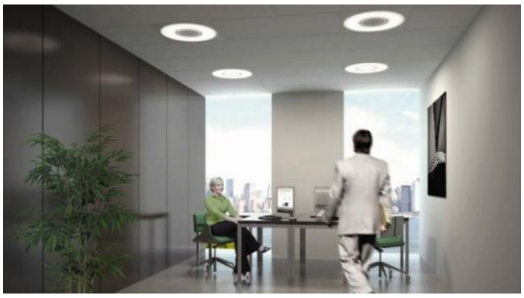

Fig. 4. Philips DayZone luminaire (system) in an office application. One of the earliest functional LED office luminaires applied in a ceiling. Luminaires at window side are switched on in the 500 lux setting, the two luminaires in front are switched on according the 300 lux setting.

The project scope was well defined: 'Bringing an Office LED luminaire to the market, delivering good quality lighting (complying with norms), breathing innovativeness of LED technology and offering the best energy efficiency compared to other Office LED offers'. The luminaire is a typical S-Curve Transition product. It was too early to learn already from the DayWave, as this product was just introduced.

Retrospective analysis shows less severe, however, still significant conflicts with the TRIZ S-curve evolution laws:

- *Recommendation from TRIZ: replace the engine, and make it work.*
  Indeed, the housing of traditional luminaires has been reused, including significant part of the optics. However, instead of one light engine, 2 separate engines have been brought in, which could work independently and create a so called 300 lux / 500 lux solution, a system so far not realized by traditional fluorescent lighting.
- *Recommendation from TRIZ: Select a real champion parameter.*
  As champion parameter 'best efficiency compared to other Office LED offers' was chosen. Decision of customers was based on a comparison related to traditional fluorescent lighting solutions. This lighting solution outperformed the newly introduced DayWave system, however, not the traditional lighting systems applied in offices.
- *Recommendation from TRIZ: prepare for future upgrades.*
  It has been foreseen in the design of the luminaire that upgrades are easy possible when better (= more efficient) LEDs become available. Replacing the LED engine would not require a complete redesign of the product. A real improvement compared to the DayWave.
- *Recommendation from TRIZ: Limit the options to limit the price of the product.*
  Once again many options were implemented from the start, making the product more complicated, thus more expensive than desired. The representatives of the sales groups even requested more options like integrated controls, matching all suspended ceilings and more.

In conclusion the DayZone is a nice eye-catcher, still being a functional but luxurious luminaire. Due to the complexity and the peak design LED engine, the introduction price was pretty high, with limited potential to bring this down. Hesitating sales figures resulted in a limited success and the product did only partly bring the break-through in LED-Office that was anticipated.

2.3. A third functional office luminaire, respecting major aspects of the S-curve TRIZ theory.

Fig. 5 shows an application where a second functional office lighting luminaire has been applied. Once again a luminaire with a deviating shape and interesting features and functionality has been developed and introduced to the market. It was during the definition stage of this luminaire that the S-curve methodology was implemented.

The design brief of this project was clear: "Best in class in energy performance, delivering good quality lighting while respecting all office lighting norms". The luminaire is a typical S-curve 2nd phase luminaire: a move into the direction of mass production, a higher variety of engineering systems become available. Learning's from the two previous introductions have been effectuated.

Fig. 5. Philips PowerBalance luminaire, the breakthrough in functional LED office lighting. The left picture shows the first generation, the right picture shows the second generation.

An analysis on basis of the evolutionary TRIZ S-curve laws shows why this product was well received in the market and has become a benchmark in the lighting industry.

- *Recommendation from TRIZ: replace the engine.*
  The housing as super system of the traditional lamp has been reused. Where technically possible, existing components have been re-used, including the interface to ceiling systems.
- *Recommendation from TRIZ: make it work, and make it better.*
  This was realized by the availability of highly efficient LED engines. This combined with an optical system with a very high efficiency and adequate glare characteristics made the luminaire outperforming traditional lighting solutions.
- *Recommendation from TRIZ: select the real champion parameter.*
  Efficiency (lumen/Watt) was chosen, from point of view from the decision makers in office lighting projects the dominant aspect, both for renovation projects as for new installations.
- *Recommendation from TRIZ: limit the number of options.*
  The first generation of the luminaire had limited options, resulting in a cost conscious design aimed to replace on 1-to-1 basis existing luminaires in the field. Due to limited cost and the high performance even with the limited annual burning hours in offices, a pay-back of 3 years could be realize. The next generation, introduced 2 years after the first launch, could be improved on various aspect: even higher efficiency, nicer aesthetical appearance, and options like daylight and presence sensors including lighting control, emergency lighting and superb optical characteristics.

This PowerBalance recessed functional office lighting luminaire developed respecting the TRIZ S-curve rules has been introduced very successfully in the market. Sales went up according the expectations, improved generations succeeded the first generation and spin-off luminaires have arrived at the roadmap, or are in mean time introduced.

3. Two examples of luminaires designed for the industry segment

Lighting conditions in industry do not always get the attention the industry workers deserve. Old and simple lighting installation are common, the focus is on the primary industrial process, neglecting good visual working conditions for the employees. “Good lighting means better work” is a nice phrase, recognized in the industry, however, more often neglected than applied. Question was how, where and why to introduce LED lighting in the industry segment. Especially the continuous pressure on low-low costs has been a concern. As LED lighting is potentially more energy efficient than any traditional lighting, the long burning hours in the industry might help introduction of long-lasting energy-saving lighting eliminating or strongly reducing maintenance. Two examples of successful approaches for general lighting in the industry are described. The first one should be timed in the transition phase; the second example is reflecting the 2^{nd} stage.

3.1. Dual luminaire development, a luminaire suitable for traditional fluorescent and for LED lighting.

LEDs were coming up, however, considered to be unaffordable for the majority of the projects in the industry market. However, very interesting benefits for LED lighting could be addressed for certain niche markets.

In the waterproof luminaire segment the demand for a specification luminaire on basis of TL5 fluorescent lamps was confirmed. At the same time, introduction of LED in waterproof luminaires has been considered. In the idea development, with guidance of the TRIZ S-curve evolution laws, interesting considerations concluded the feasibility of LED in waterproof for a limited part of the market.

Fig. 6. Philips Waterproof luminaire in two variations.
Left the version with traditional fluorescent lamps, right the version equipped with LEDs. Both make use of the identical housing, end-caps and mounting clips.

The outspoken champion parameter in industry is lumen/Watt, resulting in lowest running costs for the principle. Fluorescent tubes do not perform well under low-temperature conditions, while LED lighting performs remarkable well under freezing conditions e.g. in warehousing for the food industry. A champion parameter was born: efficiency at low temperatures.

Developing a luminaire for this niche market only, did not have a positive business case. This was reason to join forces with the development of the TL5 fluorescent high-end waterproof luminaire. Figure 6 shows two versions of the waterproof luminaire. Both make use of the identical super system (housing) for the light engine. The luminaire design secures even that in a later phase, when LED has become more efficient, a LED engine could exchange the traditional TL5 light engine.

Analyzing the Pacific LED luminaire from TRIZ S-curve evolution laws shows interesting aspects:

- *Recommendation from TRIZ: Replace the engine.*
  For this luminaire this recommendation was taken very literally. The identical housing can hold the TL5 fluorescent light engine or the LED light engine. Exchange is possible within a minute, facilitating future upgrades to a LED version, or even to a next generation LED release.
- *Recommendation from TRIZ: Make it work.*
  This resulted in just 2 beams of light for the LED solution, a wide beam and a narrow beam. Both required for the chosen application segment 'cold stores'. Full focus has been given to the champion parameter lumen/Watt, outperforming immediately any fluorescent solution at low temperatures.
- *Recommendation from TRIZ: Make it cheaper.*
  The mechanical and electrical design anticipated future more efficient LED light engines. While the first generation offered a limited amount of light at high costs, all next generations resulted in significantly lower costs, at higher performance. An optical contradiction was solved: if you have better optics than you achieve lower glare, but it is more complex to manufacture. Changing over from optical system at the 3rd generation (in < 3 years) to a simpler, however more efficient optical light engine increased the performance and strengthened the champion parameter, respecting the glare figures. The champion parameter lumen/Watt improved significantly. Not only the niche application has benefited from improvements, also for standard applications like humid industries and indoor car parking the waterproof lighting system is a perfect choice.
- *Recommendation from TRIZ: Limit options at the start*
  At introduction only two light distributions were made available in two luminaire lengths. Reducing the costs for next generations freed budget space for options like longer luminaires, more light, and more light distributions. By the introduction of more efficient LED systems, public parkings have become a feasible application. A system of presence detection and further energy saving could be added to the Pacific LED system.

Now, some years after introduction of both the traditional TL5 fluorescent based waterproof luminaire and the LED based waterproof luminaire, the LED based version has become very successful, thanks to the introduction in the niche market based on a dedicated champion parameter for cold stores. Future upgrades of the light engine are anticipated, and systems are developed based on this luminaire.

3.2. Renovation light line luminaire based respecting the existing super system.

Since decades in the dry segment for industrial lighting so called trunking systems are applied. This is a very mature market and the last year's limited innovations have come to the market. The availability of LED has re-inflated the product. Figure 7 shows a typical application of light lines in industry: long lines are running in an industrial hall. Function of the trunking line is the transport of electrical energy in combination with support of the luminaire.

The trunking system is widely spread. Especially in Europe thousands of kilometers of trunking have been installed in the past 30-40 years. A LED solution has been developed respecting the current super system (trunking), facilitating renovation from old less efficient luminaires to modern much more efficient luminaires within the same system.

Fig. 7. Typical application of light line systems in industry.
Long (semi-) continuous lines of light illuminate the area.

Analyzing the Maxos LED trunking system based on TRIZ S-curve evolution laws shows interesting aspects. No conflicts with TRIZ S-curve laws are known.

- *Recommendation from TRIZ: replace the engine.*
  Only the electrical unit supplying the light has been replaced, see figure 8. A one-to-one replacement is possible in most lay-outs; however, at the start when the LED light engines were limited in the amount of light, extra LED electrical units could be mounted inside the trunking as this was foreseen in the systems designed already many decades ago.
- *Recommendation from TRIZ: make it work.*
  Due to the simple architecture of LED modules mounted on the carrier no issues have been reported. Concentration has been on ONE champion parameter, lumen/Watt. LED line lighting outperformed any previous solution from the beginning. The 4th generation of LED engines is going to be introduced; the champion parameter outperforms any conventional solution by > 50%. As burning hours are usually long in industrial application, the outperforming lumen/Watt value

accelerated the introduction as pay-back periods were sufficiently short.

- *Recommendation from TRIZ: make it cheaper.*
  Via the LED platform approach and easy and quickly to replace expensive components, interesting costs-downs have been realized. No significant redesign of the system was requested as the platform design is fully modular, accelerating cost-down and introduction. As the super system could stay in place, also for new lighting installations, no time and effort was lost.

Fig. 8. Typical light line engines integrated with trunking.
Left an example of a version based on fluorescent lamps, right an insert based on LED lighting technologies. Note the upper super system which is completely identical.

Fast market acceptance has been the result. Best compliment for the success of the system is the copy-paste reaction of some major competitors. Thanks to a thorough S-curve TRIZ analysis an excellent product could be engineered and brought to market successfully.

4. Conclusions

In the introduction period of LED lighting for general lighting purposes the TRIZ S-Curve methodology has been gradually used during the development process and the road mapping. Engineering systems introduced respecting the laws of the S-curve have been significantly better than for products where the laws were partly of not respected. Creating the road maps of the future, the TRIZ S-curve methodology will be taken into consideration to increase the success rate.

Acknowledgements

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

TRIZ-board game for waste reduction in Lean Production and Management

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Abstract

Lean Management and Lean Production are very common approaches in real business today. The methodology provides the chance to integrate TRIZ fruitfully at some points. Therefore, this topic is of special interest for the dissemination of TRIZ.
This article shows the development of a TRIZ-based board game to be used by Lean-practitioners for specific tasks of waste reduction. Besides the logic of the game, some instructional hints are given. The board game uses some TRIZ-tools and is made easily digestible for Lean-practitioners by also integrating Lean-thinking and tools.

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Keywords: TRIZ; Lean Production; board game; waste

1. Why connecting TRIZ and Lean Production?

The further dissemination of TRIZ is a goal for many TRIZ-practitioners. There may be many different motivations to do so – from individual enthusiasm up to the insight of the practical power and relevance of TRIZ tools and principles. This covers the origins of TRIZ invented by Altshuller (e.g. [1,2], as well as more recent approaches elaborated by the scientific TRIZ-community and practitioners.

In the actual practice of many companies, Lean Production approaches are state of the art in the field of problem solving in companies operations. Thus, some integration of TRIZ and Lean approaches seems to be very interesting because of the similar objectives of both methodologies. This is of special interest regarding the dissemination of TRIZ because Lean is widely spread as compared to TRIZ (see for example the presented results of internet searches at [3]).

The authors already discussed the difficulties to implement valuable TRIZ-tools in the toolset of Lean Management or Lean Production campaigns (see [4]). Besides some first lean interpretations of TRIZ-tools like e.g. the Lean operators of the 40 Inventive Principles [5], further practical approaches for the dissemination of TRIZ in Lean Productions are worth striving for.

2. Development of the board game and proposed application

The development of the game respected the insights of the authors regarding problems and chances of integrating TRIZ-tools in the Lean toolsets (see [4]) in two ways:

First, experienced Lean-practitioners have to be guided gently to new tools, that have their origins outside the Lean-world (some TRIZ-tools even are part of the Lean-toolset, but almost nobody knows). Therefore the authors decided to create the framework of a board game, to guide through a special process that uses TRIZ-tools at points, where Lean-experts can't successfully apply their own tools. The goal is to enable the learning of TRIZ without any offensive to the Lean-thinking and in a "peaceful" supporting way.

Second, the problem to solve has to be chosen in a way, that there is an absolute need in the Lean-world, to find additional supporting tools. But on the other hand, these tools must be compatible with lean thinking, the foreknowledge, the experience and wording of the target group. This led the authors to focus on the elimination and reduction of waste. Waste (or muda) is a term of art in the lean language. But waste reduction has also ever been a topic for using TRIZ (see e.g. [6]) and the fit between Lean and TRIZ in this manner has been thoroughly described recently [7].

For the board game with the working title “waste(riz)”, the following framework was defined:

- multiplayer game to foster teamwork and disseminate experience and learning
- based on real wastes to show effect in real life
- with procedural and repeating elements to enhance learning by doing
- everybody wins – no losers

The board game should be used in training situations first. This provides experience to the facilitator so he or she is able to decide if and in what other situations it can be used. Each company has a specific state of its lean-implementation, specific tools and specific cultural framing conditions. So starting in a training environment has to be preferred to see if the culture is open enough and willing to learn and adopt new methods.

3. Characteristics of waste(riz)

Based on the framework above, the actual version of waste(riz) has the following characteristics:

- Number of players: 3 to 6 players per board.
- Preparation of players: at least one player must be trained in the used TRIZ-tools and in the conduction of the game – he or she is facilitating the game (alternatively the game might be facilitated by a tandem of two facilitators).
- Initiation: to initiate the game, a list of wastes (according the Lean-lingo) found in a specific area of the operations has to be identified; therefore lean approaches like standing-in-a-circle or muda-walk (see e.g. [8,9,10]) can be used. Also the key performance indicators (see below) have to be defined.
- Goal and end of the game: the waste in the observed operation is influencing specific key performance indicators (KPI). At least one KPI (max. three) must be identified. The current state - as well as the targeted future state of the KPI’s - has to be defined. Typical KPI’s are for example the lead time, cycle time, number of defects, used space etc. (see e.g. [10]). When the KPI reach the target value(s), the game is over and everybody has won. The price is a collection of actions to realize (or already realized).
- Course of the game: the game is turn-based. A turn is defined as the work on a specific waste to reduce or eliminate it. It’s possible, that one specific waste also determines more than just one round – also it may happen that not every waste is treated during a game.

4. Rules of the game waste(riz)

As mentioned above, to initiate the game there has to be a waste observation and the wastes have to be written down in a list. At least half of the players should also have taken part in the waste observation. Another task after the waste observation is the definition of one, two or three KPI’s for the game and to decide about their current figure and the target (e.g. current: space used = 80 square meters, target: 40 square meters). Before the game starts, the facilitator has to write each waste on a waste-card (see Fig. 1) and give it a number.

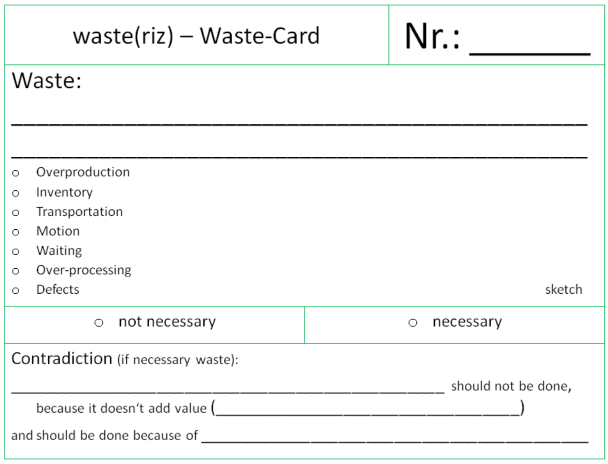

Fig. 1. waste-card template.

The facilitator sorts the waste-cards to a stack. The card at the top should be most promising in reducing or eliminating waste regarding the improvement of the KPI’s. Truly, sorting the cards this way is just an estimation of the facilitator.

To start the game, the facilitator welcomes the players and tells them about the operations area of interest, about the muda-walk (waste observation) and the KPI’s. Remember, that at least half of the players should have taken part in the muda-walk. To respect the lean-principle of being where the things happen, the game should be played at or near the particular area of operations.

The first action of the team is to write the names of the chosen KPI’s on the KPI-scales as well as the unit and the scale. The range of the scale reaches from the actual value up to a meaningful figure better than the target figure. The target figures have to be marked on the scales. One meeple (pin or flag) is set on each scale to mark the current state.

Roughly the rules of waste(riz) are:

- take a waste-card to the discuss-field and mark type of waste
- collect spontaneous solution ideas and write Before-and-After-Cards
- implement solution ideas and measure change of KPI or guess the change – indicate the change on the board
- whenever the waste of a waste-card is eliminated completely, take a new card
- if the waste on the card is not eliminated completely, it has to be marked as “necessary” or “not necessary”

- remaining not-necessary waste is treated with some of the 40 inventive principles (in the best case using supporting Lean-operators)
- remaining necessary waste is treated as a physical contradiction using the separation principles
- solution ideas are written down on BaA-cards, solutions are implemented (if possible) or their impact has to be estimated
- end the game, when the KPI-targets are reached or all waste-cards have been processed (including a second trial on cards not finished)

This rough overview catches the main point of the rules. The following paragraphs will explain the rules in detail:

So the team takes the first waste-card off the stack and moves it to the discuss-field. Players read the content and mark the type of waste. If they have some spontaneous ideas to reduce or eliminate the waste, they have to write down the ideas on Before-and-After-Cards (BaA-cards), see figure 2. Then (if possible right now) the players should go out on the shop floor and realize the ideas from the BaA-cards directly.

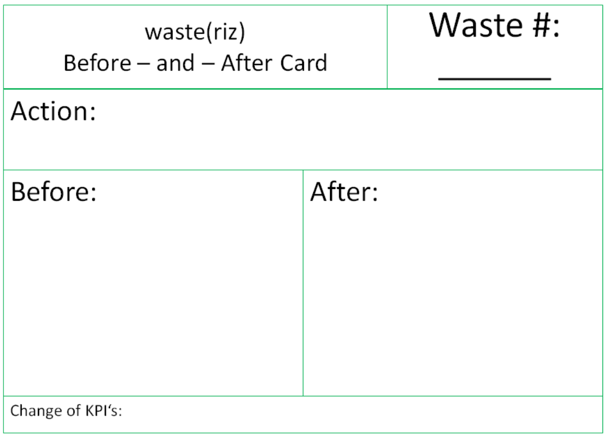

Fig. 2. Before-and-After-card (BaA).

On these cards there is also a field to document (if realizable immediately) or to guess the change of the KPI's, when the proposed improvements will be realized. Now the meeples on the KPI-scales are moved according to the realized or estimated changes noted on the BaA-card(s). The BaA-cards then are stored in the "action-area". If the waste written on the card can presumably be eliminated completely by the realization of the BaA-card(s), it is moved to the "done-field" and the next card is taken from the stack of waste-cards. If the waste is not or not completely eliminated through the proposed BaA's, the card is moved to the next field: "necessary or not".

At the field "necessary or not" the waste on the waste-card is rated as "necessary" or "not necessary" (terms of art in Lean-lingo [10]). If it is "not necessary", the card is moved to the "obvious waste"-field. If it is necessary, the card is moved to the "contradiction-field".

If a waste-card is moved to the field "obvious waste", one of the players takes one of the 40 inventive principles with lean-operators (see [5], the principles and operators should be available as a list or a set of cards) for a short brainstorming to find more ways to eliminate the remaining waste. The solution ideas are documented on BaA-cards, the meeples are moved and the BaA-cards are stored in the "action-area". If the waste written on the card now can presumably be eliminated completely by the realization of the BaA-card(s), it is moved to the "done-field" and the next card is taken from the stack of waste-cards. If the waste is not or not completely eliminated through the brainstorming, it can be repeated twice with other inventive principles with lean operators. If there remains still some waste, the card is moved to the field "second chance" and a new waste-card is taken off the stack.

If a waste-card is moved to the "contradiction-field", first the facilitator supports the team to formulate the resulting physical contradiction at the end of the waste-card. The details how to formulate physical contradictions in a lean environment out of necessary wastes is given in [7]. After that, the card is moved stepwise from separation-field to separation-field (except the waste is completely eliminated), solution ideas are documented on the BaA-cards and the meeples for the KPI's are moved. The authors propose to walk through the separation-fields in the following order: separate in space, in time, in structure and on conditions (for more separation principles see e.g. [11]). To lead the game at this point the facilitator should have some experience in resolving physical contradictions. If after the last separation-field the waste written on the card can presumably be eliminated completely by the realization of the BaA-Card(s), it is moved to the "done-field" and the next card is taken from the stack of waste-cards. If the waste is not or not completely eliminated through the proposed BaA-action, the card is moved to the field "second-chance" and the next card is taken from the stack of waste-cards.

The game is over, when all meeples indicate at least the target value. Pay attention, that any proposed action may improve a KPI but can also worsen another KPI (if so, the proposed improvement contains a contradiction as a subsequent problem – but don't address this, if people are not experienced with TRIZ).

If all waste-cards are processed but the meeples are not all at the target values or better, go back to the stack "second chance" and try the methods you didn't try before. This means: put the cards with a necessary waste to the "obvious-waste"-field and the cards with not necessary waste to the contradiction field and try to formulate a physical contradiction. After this second chance, each of the cards should be moved to the field "done". If all waste-cards are located at "done", the game is also over.

5. Additional notes and TRIZ-tools used

After finishing the game, the action-area contains the tasks that have to be fulfilled in the particular area of operations to reduce or eliminate waste and to reach the targeted KPI's. The lean-practitioners know how to work with the BaA's.

The TRIZ-tools used in waste(riz) basically are:

- the 40 inventive principles and the appropriate lean-operators (see e.g. [12,5])

- the separation principles (see e.g. [11,12]), whereas the formulation of physical contradictions out of the lean types of waste is helpful [7]

The facilitator – especially regarding the task of resolving physical contradictions – needs some TRIZ experience and knowledge. This has to be considered. At this point he or she could be supported by using the appropriate sections of a TRIZ-software. If so, the software is only used by the facilitator while facilitating the group to resolve the physical contradictions.

The board of the board game should be drawn on brown paper by hand. Thus the style and the exact caption may vary. Figure 3 shows the logical connections for the normal processing of the waste-cards.

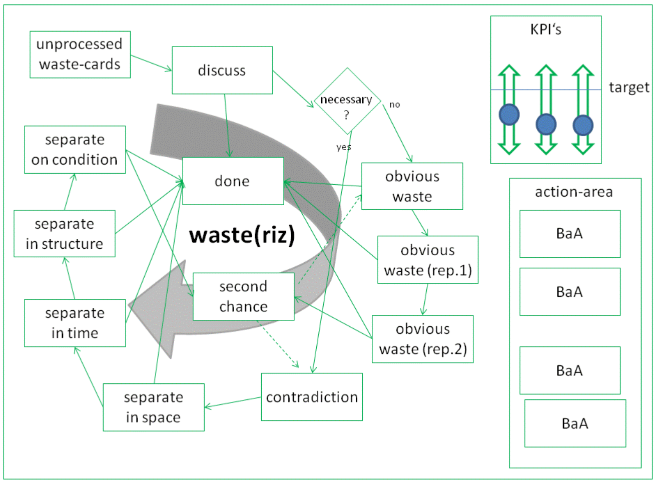

Fig. 3. waste(riz) board logic for waste-cards.

6. Conclusion

The waste(riz) board game is developed to introduce TRIZ-tools and TRIZ-thinking in a lean environment. Contents, motivation, goals, and procedures fit very well with common lean aspects and principles. The way of doing is very close to some working form out of the lean world. The process of the game guarantees, that TRIZ-tools are used when needed and not as an end in itself. Lean-practitioners start knowing and using TRIZ-tools and their experience and insights regarding TRIZ is growing. The extended elimination of waste supports their basal activities.

Based on the constitutive thoughts of the authors, the board game is still under development and testing at the Competence Center OPINNOMETH at the University of Applied Sciences Kaiserslautern. The concept and the insights will be published completely there after finishing some testing at free disposal.

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Trend of increasing coordination in biology

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Abstract

For the development of micro injection needles, a study has been conducted examining the architecture of comparable biological structures. These structures comprised poison fangs of vipers, Komodo dragon, mammals, the venomous spur of the duckbill platypus, the sting of the stingray, chelicerae of spiders, and the hornet sting. Comparison of the existing technical design with the biological correspondents has led to a new approach of designing a miniaturized needle.
Moreover, comparison of biological injection devices yielded various basic designs differing mainly in how the venom is conducted to the punctured tissue: Whereas the Komodo dragon applies its venomous saliva along the surface area of its teeth, the solenodon features a grooved tooth, thus guiding the saliva along a linear structure. Vipers, platypus, spiders, and wasps finally possess venomous glands from which the poison is released punctually via closed canals.
As we take the observed 2D, 1D, and 0D distribution structures, they may correspond to the cost of venom production with the least valuable venom being applied on a surface and the most valuable at a single point. This interpretation supports the rule of "Coordinate Action" (subtrend no. 4 to the Trend of Increasing Coordination) according to which a little available resource is applied punctually (0D) whereas excessively available resources make use of high dimensional application space.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: TESE; Trend of increasing coordination; trends of enginering system evolution; bionics; law – antilaw; bionics; venom; injection needle

1. Introduction

One method to administer medicine to patients is transdermal drug delivery. Transdermal drug delivery permits fast drug administration without the high uncertainty of absorption in the body which is encountered in traditional administration via the gastrointestinal tract. On the other hand, the barrier function of the upper skin layers blocks off the passage of most substances. We have therefore designed an array of hollow micromachined needles which penetrates the outer skin layers and delivers pharmaceuticals to blood vessels in the dermis, the lower skin area. A cost-efficient process for manufacturing the array by means of hot embossing has been developed with the first experiments being performed using micro-milled brass needles [1] (with further literature).

2. Needle design and first tests

The injection needles feature a nearly cylindrical puncture section of ø 0,3 mm, followed by a conical pedestal to increase the buckling resistance, Fig. 1:

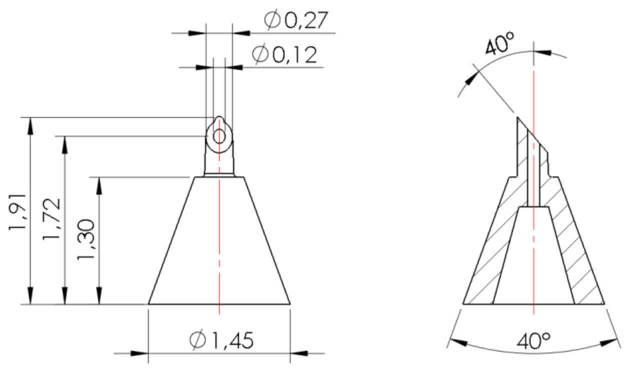

Fig. 1. Microneedle, dimensions in mm

To sharpen the needle, it is chamfered by an angle of 40° and augmented by a small tip protrusion. The needle contains a bore of ø 0,1 mm. The needle array prototype consists of a square baseplate with edge lengths 7,35 mm carrying four needles. This array is inserted into a housing box which carries tubes ø 1,6 mm for fluid supply, Fig. 2:

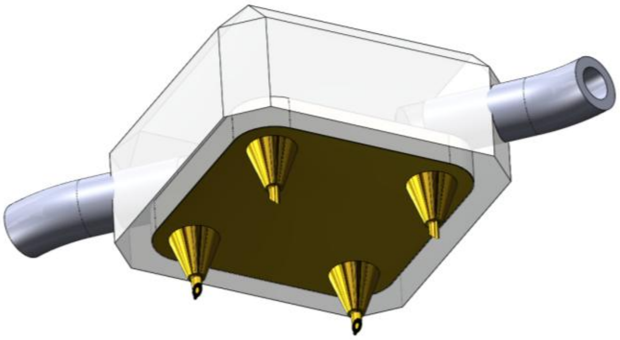

Fig. 2. Connection box with needle array and tubing.

One of the tubes is connected to a syringe pump producing the injection pressure, the other was provided for further laboratory test aspects, e.g. for air vent.

Tests of the arrays comprised experiments on pig ear skin; at these, the array was pressed onto the skin at a predetermined force, then a tinted liquid was injected, while the flow rate and pressure in the tube were measured.

First tests occasionally yielded an uneven pattern of injection success as reproduced in Fig. 3. The blurred mark on the lower right indicates that ink was not properly injected but spread out between skin and needle.

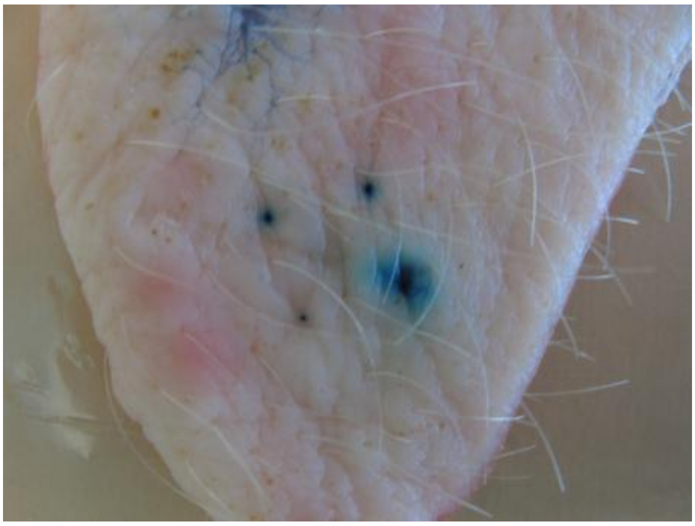

Fig. 3. Pig's ear with injection marks.

This variation in success of injection was attributed to local variation in skin properties, but also to plugging of the needle by skin particles. The used design of the needles contains two cutting edges on the needle face which can – and do – cut out a small area of skin surface which may then obstruct the needle bore, Fig. 4.

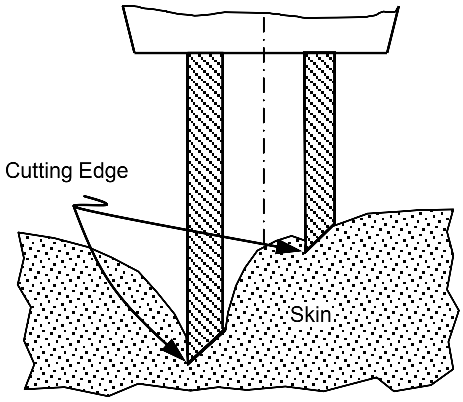

Fig. 4. Schema of needle entering the skin.

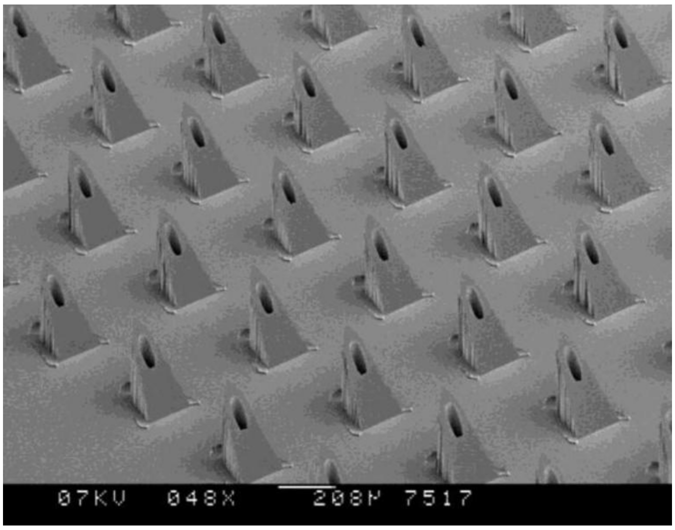

Fig. 5. Microneedle array etched from silicon [2].

Other microneedles published by other groups feature a similar basic design, Fig. 5. One must therefore suspect the same problem appearing there

3. Contradiction

In TRIZ formulation, one possible physical contradiction is "There must be an opening in order to deliver fluid, BUT there must not be an opening in order to avoid clogging".

3.1. Separation in space

- The opening must be at no special location, as long as it is under the skin surface.
- The clogging happens where the skin is compressed.
- *→ Move the opening to a location where the skin is not compressed i.e. to circumference of the needle* – unfortunately, this is not possible for technological reasons: Both injection moulding and hot embossing demand features to be formed along the vertical axis.

3.2. Separation in time

- The opening is needed when the needle has entered the skin.
- Clogging occurs during the entering process.
- → *Produce the opening after the needle has entered the skin* – changing the micromachined structure during operation does not seem viable. An option might be to prevent skin particles from entering by high fluid pressure inside the bore. A corresponding attempt did not prove successful, though.

3.3. Separation in relation

- The opening must be permeable for fluid ...
- … and impermeable to skin.
- → *cover the opening by a sieve or use a porous structure* – the opening is made with an open diameter of 100 µm, less is not possible with the technology used. A porous material may be an option for the future, but if it is overlaid with compressed skin, it may be impermeable somehow.

3.4. Separation in system level

- There is no opening in the single structure, so nothing can be clogged, but …
- … the opening is formed on a larger scale
- → *a direct means of implementation of this suggestion was not seen. In a wider sense, scratching the array over the skin would provide access to deeper skin layers* – but producing a graze is not a desired solution.

By solving the physical contradiction, TRIZ evidently suggests solutions but these do not seem viable. On the other hand, there are injection needles in nature which perform successfully. How has the problem of clogging been solved there?

4. Injection needles in nature

Various animals and plants possess organs intended to puncture a surface, i.e. animal skin, wood, etc., and then to deposit material like poison or eggs. A limited internet search yielded the following examples:

4.1. Snakes

Vipers possess fangs with different types of canals (no groove, partially closed groove, all-round closed canal, cf. [3] pp. 254) which direct the venom to the bite. The canal opens on the outer surface of the fang, Figs. 6 (presumed skin surface sketched by the authors) and 7 ("*A and A1 grooved tooth, B and B1 tubed tooth; G venom channel, and P pulpa cavity"[4]*).

4.2. Komodo dragon

The komodo dragon, a large reptile living on Indonesian islands, is known for its bite causing severe sepsis which will

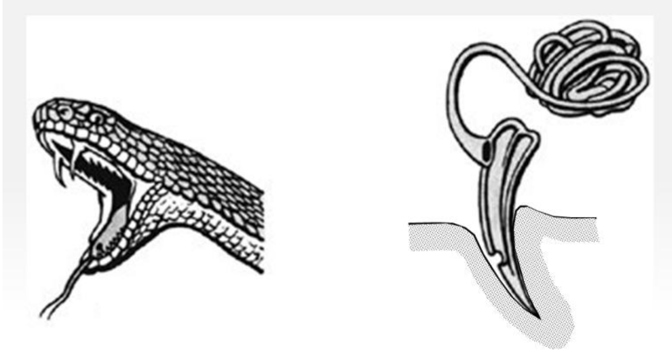

Fig. 6. Head of common viper (left), fang with canal (right) [4].

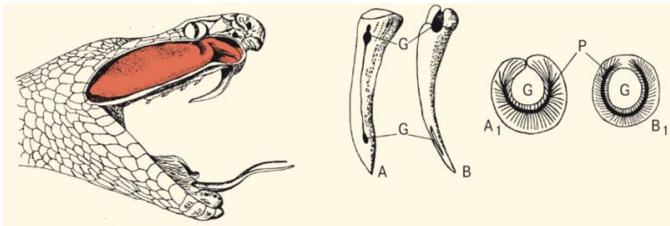

Fig. 7. Head of rattlesnake [5] with venom gland (left) and fangs (right).

eventually lead to the death of the prey. The exact composition of the venom and the share of bacteria in the saliva and in the environment are under debate; Fry at al. however report that toxic components in the saliva together with the serious bite kill the prey [5]. Photographs of teeth of contemporary animals do not feature any tubes, grooves or other venom-related structures, Fig. 8 (the left part of photograph (B) is inside the teethridge). An extinct species, *Varanus (Megalania) priscus*, did feature grooves, though not prominently.

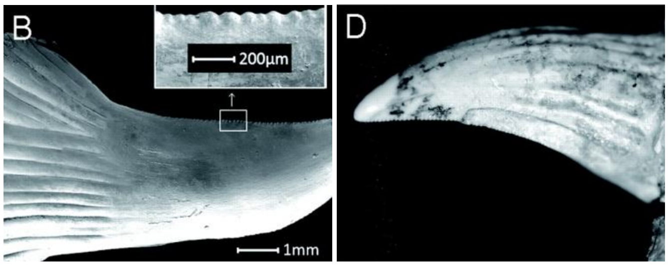

Fig. 8. Teeth from Varanus komodoensis (B) and extinct Varanus priscus (D) [6].

4.3. Mammals

"Among the contemporary mammals, only the solenodon (solenodon paradoxus) and certain marsupials (*and a few shrews (Soricidae) [10]*) produce a neurotoxin; it is produced by salivary glands in the mandible and directed into the body of the victim though a grooved incisor tooth" [7], Fig. 9.

Already in the age of tertiary, 60 million years ago, small mammals with venomous teeth were existing; fossil teeth contain distinctly grooved corner teeth, Fig. 10 [10].

Fig. 9. Piece of solenodon mandible with grooved incisor (arrow) [8].

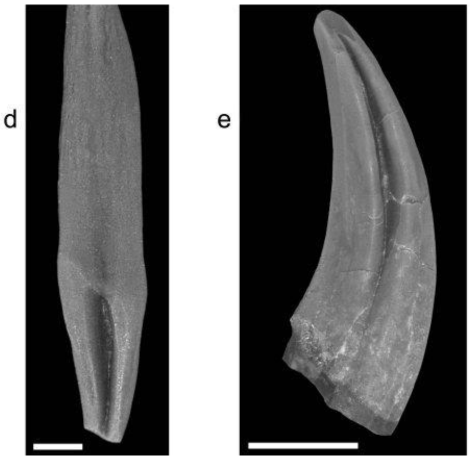

Fig. 10. Fossil corner teeth [10]. White line in (d) equals 1, in (e) 5 mm.

Platypus: Male duckbills carry a spur on their hind leg, Fig. 11 [11]. As is visible from the figure, the spur contains a closed canal connected to a venom gland.

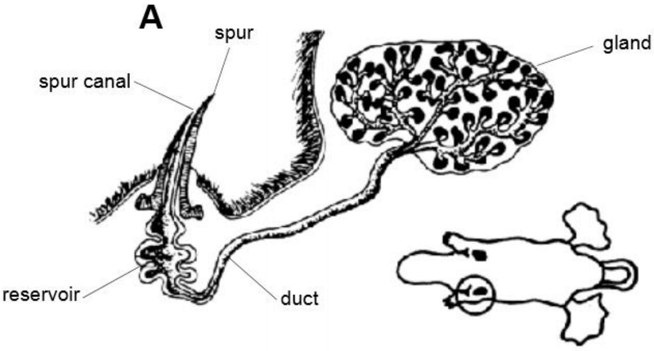

Fig. 11. Hind leg of platypus with venomous gland and spur [11].

4.4. Fish

Stingrays possess a sting on their tail, directed backward. “The sting itself consists of chalk; it is armoured with small saw-like barbs along its sides. These barbs will rip an irregular wound healing only slowly. The venom is produced at the base of the sting by venom cells and probably two venom glands; they are connected to mucilage producing cells which will transport the venom to the sting. It there accumulates under the thin sting pellicle. When the pellicle is violated, the venom will enter the punctured skin together with the sting“ (ray breeder’s description [12]).

As is visible from Fig. 12 and as was confirmed by our own investigations, the sting skeleton features a pair of parallel grooves on its upper and lower side. Moreover, the skeleton is so porous that fluid was transported through the structure by capillary forces. This may be different in a live sting, though.

Fig. 12. Chalk skeletons of stingray stings [12].

4.5. Spiders

Spiders (Araneae) possess venomous glands in their chelicerae (fangs). The venom canal opens shortly in front of the tips of the chelicerae, Fig. 13.

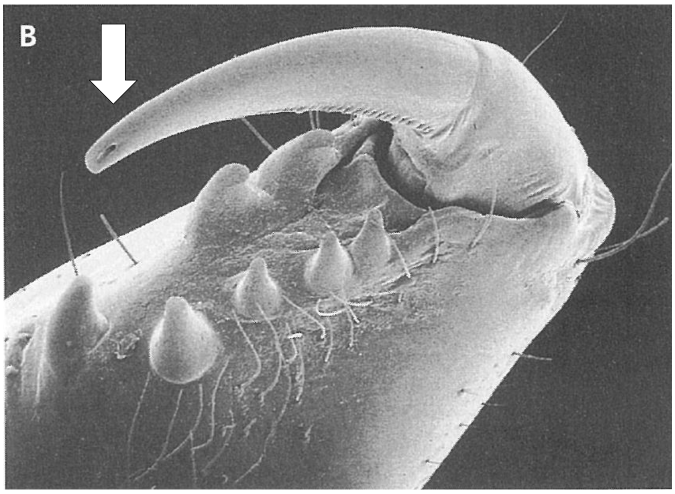

Fig. 13. Meta menardi (Araneidae), chelicera with canal outlet [13].

4.6. Movable and breaking stings

Insects like bees, wasps, hornets, sawflies, or mosquitoes possess stings with moving parts, generally with one saw-like structure working against the other, thereby compensating the penetration force inside the sting system, Fig. 14. Since moving elements are not an option for the required type of microneedles, they are not considered further.

Neither are breaking stings as are featured by sea urchins, some caterpillars, or stinging nettles.

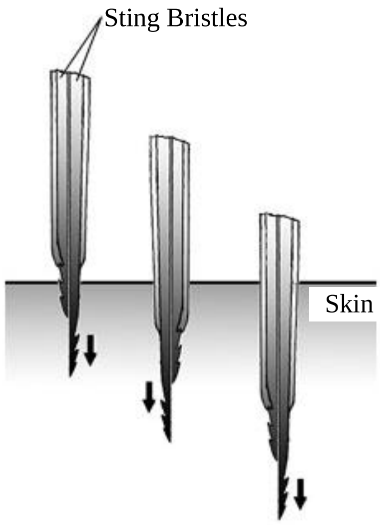

Fig. 14. Schema of hornet sting function during penetration [14].

4.7. Design types in nature

From the types of stings described above, we have identified four basic designs:

1) Closed canals with passive outlet (tubular teeth, platypus spur, chelicerae) – the outlet never appears at the tip of the sting but on its side
2) Open canals with passive outlet (grooved teeth) – when venoms are not contained in tube-like structures but in distributed form (venomous saliva), tubular canals do not seem advantageous.
3) Closed canals with outlets opening during injection (stingray) – a blade structure contained in the sting passively cuts though the sheath; this ensures that the venom enters a puncture wound.
   Bees and other insects actively move sliding parts of the sting; between these, the venom is delivered.
4) Closed canals being opened by the process of injection (caterpillars, nettle) – the mechanically highly stressed venom tube breaks during injection and the venom is delivered into the wound.

4.8. Applicability of biologic designs for a microneedle

Active needle structures, e.g. with bristles pairwise acting against each other, are difficult to implement by micro machining. The insects do not carry the corresponding actuator at the tip but at the base of the sting; a microneedle would therefore also need an additional actuator for relative movement. The advantage of this setup is the low force acting on the complete system.

Needles using the principle of the viper tooth can basically be realised by precise or micro mechanics. They are characterized by a curved movement of the tooth with the canal outlet lying on the outer side of the tooth. At this position, a gap between tooth and tissue is more likely to occur than compression, so the risk of clogging is low.

Open channels as with grooved teeth are the easiest to manufacture since no micro bore is required. A difficulty here lies in sealing the needle. Animals do not need sealing because enough venomous saliva is present around the tooth.

Very promising seems the design of the ray sting. The sealing and puncturing functions there are divided between the chalk skeleton and the surrounding sheath. Due to the sharp edge of the skeleton, the sheath is made sure to tear exactly inside the wound. A technical sting might therefore consist of a spike without a bore, covered by a thin foil. At the moment of injection, the foil is punctured and delivers the medicament. Variants of implementation of this principle are shown in Fig. 15:

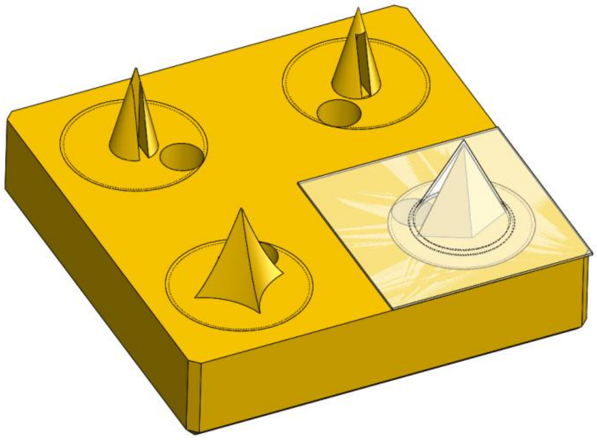

Fig. 15. Variants of a technical microneedle based on the stingray design.

5. Venom injection and the trend of increasing coordination

Henry Altshuller, the creator of the TRIZ methodology, has postulated the existence of several laws of the development of technical systems [15]. These rules indicate that technical systems – i.e. systems made for a purpose – possess a tendency to evolve in certain directions. Some of these laws are evident like *(1) the law of completeness of the parts of a system*, others may seem plausible, but the law behind the observation is not quite understood yet. Moreover, cases have been observed in which the observed direction of evolution does not seem to comply with the laws [16]. The denomination has therefore changed to “Trends of Engineering Systems Evolution, TESE”. There have been several attempts to fit the TESE into a system, one of the latest being by Ikovenko [17]. In his classification, the Trend of Increasing Coordination is subordinated to the Trend of Increasing Value, Fig. 16.

After Ikovenko, the Trend of Increasing Coordination has four subtrends:

1) Coordinate shapes
2) Coordinate rhythms
3) Coordinate materials
4) Coordinate actions (0D → 1D → 2D → 3D)

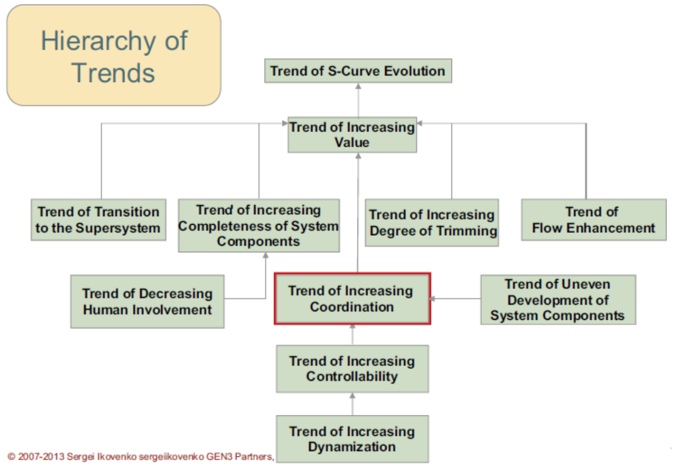

Fig. 16. Trend of Increasing Coordination in System of TESE [17]

Subtrend 4 has been observed to proceed in both directions: Towards higher dimension and towards lower. As was found, a useful function with sufficient resources will tend to evolve towards higher dimensions (e.g. car park from one parking space to multi-storey car park) whereas deficient resources will lead to higher resource concentration (paint tank → paint a single spot), Table 1:

Table 1 Direction of subtrend 4 [17]

		Resource availability	
		Excessive	Deficient
Effect	Useful interaction	0D → 3D	3D → 0D
	Harmful interaction	3D → 0D	0D → 3D

From the position of the venomous animal, the delivery of poison is a useful function. The resource in this case is the available venom. As has been observed above, animals which produce their venom in specialized glands and keep the venom undiluted (deficient resource) tend to develop closed-canal teeth or spurs (viper, spider, platypus). The venom is then administered at one single spot (0D). Animals with unlimited venom (komodo dragon) will deliver the venom over the whole area of their teeth (2D) or mouth (3D) and animals with moderately limited or dilutable venom will produce grooved teeth (1D).

We must admit that we do not know for sure if for a viper or a spider their venom is a deficient or an unlimited resource but the time venom takes to be produced and the fact that duckbills do not produce venom at the same rate over the year [11] suggest the former.

6. Conclusions

The designer of a technical system is always subject to the “inertial vector”, i.e. limitation of creativity to known solutions. By means of a bionic study, we have been able to invert an unsatisfying solution (needle with central bore) to a promising one (spike without bore). This solution also implements suggestions which were received by solving TRIZ contradictions but which had nevertheless initially seemed unviable.

Finally, the observations made at this study support the hypothesis of the “trend of higher dimensions” (subtrend 4 to trend of coordination) to depend on function type and availability of resources and additionally may provide insight to the cost of a function of an organism regarding the developed biological structures.

Acknowledgements

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TRIZ FUTURE CONFERENCE 2014 - Global Innovation Convention

Redesign of a Bearing Extractor Tool for an Aircraft Engine, using Reverse Engineering and TRIZ

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Abstract

The redesign of a roller bearing extracting tool is accomplished by means of the application of several design methodologies, such as reverse engineering as the main method, QFD, functional analysis, functional and geometrical dimensioning and tolerancing, the contradiction matrix formalism of TRIZ, FEA and DFMA. The necessity to develop a new set of tools arises from the lack of the adequate tooling for hands-on laboratory work and maintenance activities on an aircraft turbo fan engine as part of academic activities. The tool under development aims to remove a roller bearing mounted on the front hub of the front compressor rotor, as well as its sub-assembly accessories. The reverse engineering process is applied to a lent bearing puller specifically developed for this engine. The combination of design methodologies allow to propose a new bearing extractor tool, with mayor easiness on its manufacture and operation and with another operating principle.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: Bearing extractor; design methodology; functional analysis; redesign; reverse engineering; QFD; TRIZ

1. Introduction

As part of academic and research activities sustained at the Aeronautical Engineering Faculty of the National Polytechnic Institute (IPN) of Mexico, it is intended to implement maintenance, overhaul, engineering and inspection tasks on a JT8D-7B donated by Aviacsa airline [1]. In order to do so, several hardware is needed: inspection and assembly fixtures; lifting and support equipment; gearbox strip, assembly and inspection tooling, etc. This research intends to contribute to this objective by redesigning a bearing extractor for bearing No. 1 located in the front compressor hub. In order to achieve this goal, the proposed method deals with the reverse engineering (RE) process of describing the technological principles of a bearing extraction tool through the analysis of its functions and operation. The methodology is in accordance with [2], a reference that deals with the RE that has been widely used within the academia [3], as well as local heavy industry (hydraulic cylinders manufacturer).

The JT8D turbofan engine was produced in the decade of the 60's for civil mid-range aircraft, mostly Boeing 727s & 737s, and McDonnell Douglas DC-9 & MD-80s series. The JT8D engine depicted in Fig. 1a is an axial flow front turbofan engine having a thirteen stage split compressor, a nine can-annular combustion chamber, and a split four stage reaction impulse turbine. The JT8D-7B is rated to 62.3 kN (14,000 pounds) of thrust at baseline atmospheric conditions. The low pressure system is made up of the front compressor rotor and the second, third and fourth stage turbine rotors (in blue color); it is mechanically independent of the high pressure system which consists of the rear compressor rotor and the first stage turbine rotor [1], i.e., it consists of a two spool system (in green): the first six low pressure compressor stages are attached to the three low pressure turbine stages by means of a shaft; the high pressure compressor and turbine stages have the same configuration, cf. Fig. 1b.

The low pressure compressor system of the JT8D-7B engine is supported by four anti-friction bearings: No. l at the front of the engine; No. 2 behind the front compressor rotor assembly; No. 4½ and No. 6 at both sides of the turbine rotor, respectively. The high pressure compressor system and its related turbine rotor are mounted on three anti−friction bearings No. 3, 4, and 5.

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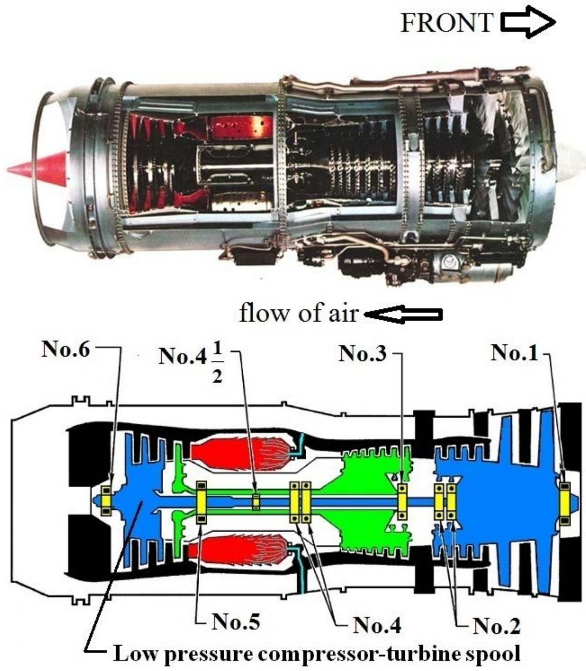

Fig. 1. (a) Engine cutaway. (b) Low and high pressure dual spool arrangement with bearings.

This document is divided as follows. In section 2 it is described the current emplacement of the bearing to be extracted in the JT8D engine; in section 3 a description of the bearing extractor tool is given; in section 4 the redesign methodology is explained in detail; in section 5 this methodology is developed for the bearing extractor tool under development; in section 6 the innovations achieved by using this methodology are highlighted. In section 7 the final conclusions are given.

2. Bearing emplacement

Bearing No. 1 employs a one piece cage, a recessed race ring and a plain raceway ring (cf. Fig. 2a); the rollers in the bearings are crowned in a conventional fashion. As the engine is equipped with an oil dampened No. 1 bearing, its configuration has a larger bearing outer race (ring no. 1b) hold by bolts (no. 10); it has lugs on the front face that are incorporated for locking with a retaining plate (no. 8), and puller grooves so as to hold metal seal rings. The main shaft seal (or air seal; no. 5) is of labyrinth type; it is a stainless steel seal with multiple knife-edges mounted on the front hub of the front compressor rotor (no. 3). This seal rotates inside of a multi-platform seal ring (no. 6), made of aluminum, positioned inside the No. l bearing front support. In front of the knife-edge seal, an oil slinger (no. 4) made of steel is positioned behind the No. l bearing inner race (no. 1a) on the front hub. Bearing assemblies No. 2, 3, and 4 consist of ball thrust bearings (cf. Fig. 2b).

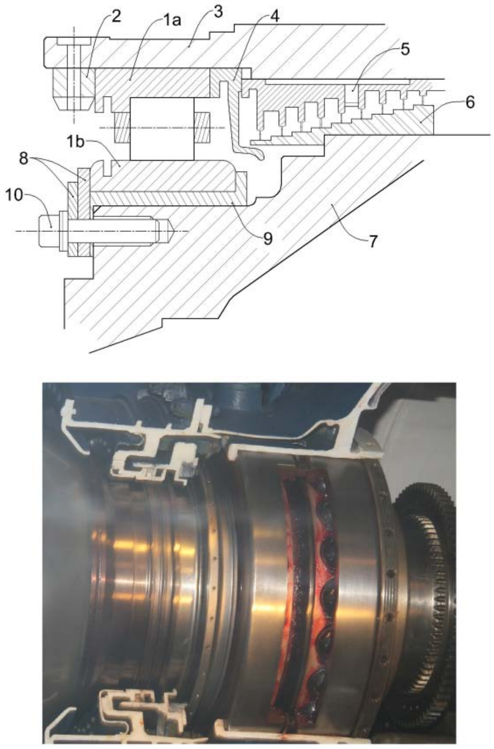

Fig. 2. (a) Roller bearing assembly. (b) Ball bearing No. 4. Picture courtesy of Museum Science & Industry Chicago.

3. Bearing extractor tool

The extractor tool (cf. Fig. 3a) consists of a full-threaded hexagon head screw (no. 17) installed into a circular platen (no. 14). The body of the extractor consists of a tri-segmented cylinder (no. 12, cf. Fig 3b) attached to the circular platten by Allen head cap screws (no. 13); the segments are allowed to move radially outwards being limited by the internal diameter of a rectangular cross-section metallic ring (no. 11) that holds the three segments together. The hexagon head screw sits on a circular stepped cap (no. 15) that fits inside the inner diameter of the front hub of the front compressor rotor; it is allowed to rotate by means of a swivel cap (16).

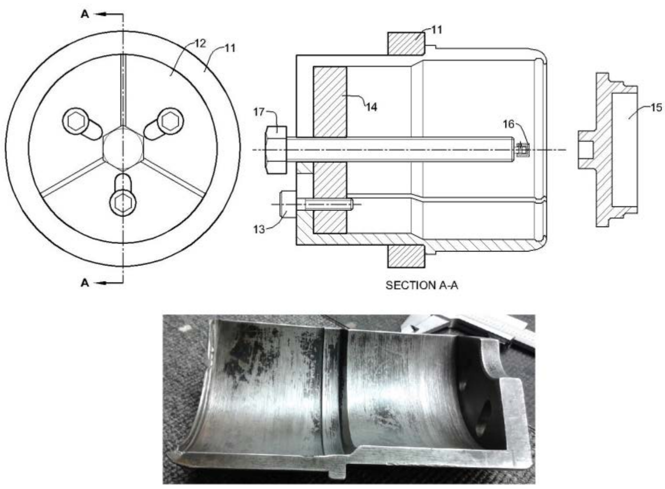

Fig. 3. (a) Bearing extraction tool. (b) Segment (cylindrical).

The bearing extractor tool is mounted on the front hub of disc #1 by means of the circular stepped cap. Then the assembly of the full thread hexagon head screw with the circular platen and the tri-segmented cylinder is mounted as shown in Fig. 4 onto the bearing inner race. Extractor bearing tool is mounted and aligned with engine's central axis, and its gripping edge is in place inside the puller groove.

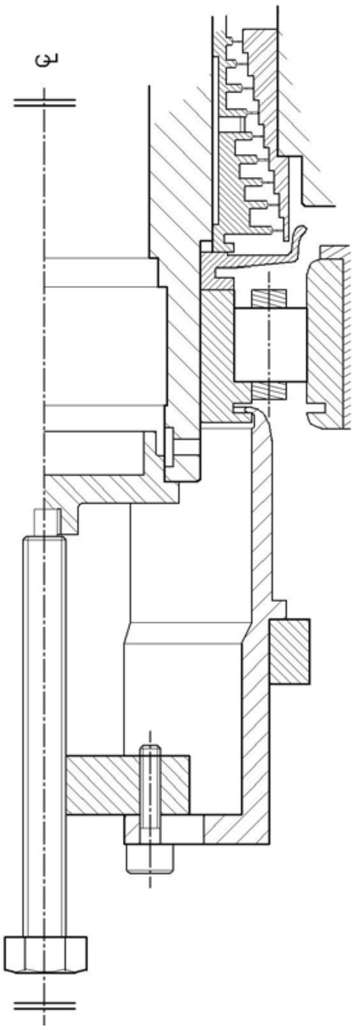

Fig. 4. Extraction of bearing No. 1.

4. Redesign methodology

The methodology to be used considers RE [2], as further detailed in Fig. 5, and innovation techniques, such as TRIZ [4]. With respect to the redesign of the extraction tool, the identification of the need is achieved by means of the Quality Functions Deployment (QFD) methodology [5]. Its objective is to express the requirements of a product, expressed as a series measurable parameters inferred from the custom requirements. It allows to better understand the design problem, so that is the reason to consider it for this research. The first step of the RE problem deals with a Functional Analysis (FA). It is a fundamental tool of the design process that explores new concepts and defines their architectures, allowing to specify the functional requirements of a new product, to map its functions to physical components, to guarantee that all necessary components are listed and that no unnecessary components are requested as well as to understand the relationships between the new product's components, [6].

Within the project design step it is possible to improve to a certain degree of innovation. It is in this step where the TRIZ (Theory of Inventive Problem Solving, or TIPS) methodology is considered. For TRIZ, the creative process that leads to the innovation of technological systems is not a random process that depends on the creativity of an individual person. In order to use TRIZ, the inventor has to adequate the stated needs (as a free language) to the language of the methodology (contradictions, patterns, principles or standards) [4], [7], [8]. Effective solutions are achieved when a contradiction is solved, either a physical or a technical one. Contradictions occur when a characteristic, feature or parameter of a technical system are improved causing to deteriorate another one. A compromise solution is then considered. A technical system has several inner characteristics or parameters such as weight, size, color, speed, etc., which describe the physical state of the technical system and help to determine technical contradictions. Then, the 40 Principles are used to resolve those technical contradictions. On the other hand, physical contradictions appear when a property of the system affects itself; several methods are used to solve them [4].

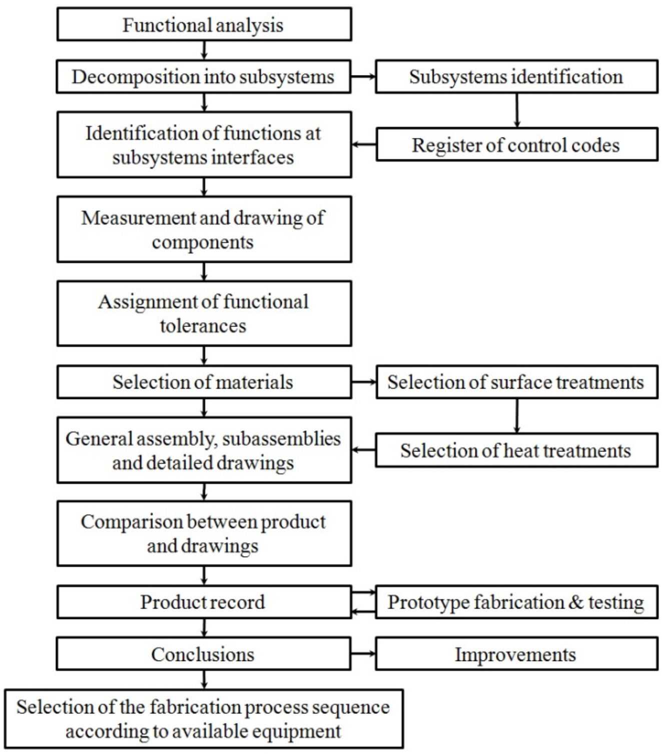

Fig. 5. Reverse engineering methodology for the bearing extractor tool.

5. From customer requirements to extractor redesign

The establishment of the design requirements, and the bench marketing are realized considering the bearing extractor tool property of Aviacsa airline, and similar bearing/seal extractor tools that were analyzed as part of a bench marketing analysis [9], [10], [11] integrated in QFD. QFD allows to consider the customer requirements, in this case, the academic personnel and technicians in charge of the maintenance, overhaul, engineering and inspection tasks on a JT8D-7B. The customer requirements already hierarchied are listed in Table 1 [12], as well as the quantification criteria for each requirement.

Table 1. Custom requirements as obtained by following the QFD methodology [12].

No	Requirement	Quantification criteria
1	*The bearing extractor may be introduced within the available empty spaces of the front hub of the disc # 1 of the JT8D engine.*	Outer and inner diameters
2	*The gripping edge that penetrates the bearing may be introduced within the slots of the bearing, the oil slinger, and the air seal.*	Geometry
3	*Its usage may be safe.*	Length and thickness of the gripping edge
4	*It may be resistant.*	Avoid sharp edges by using chamfers or radius
5	*Its components may be commercially available.*	Yield stress of the material
6	*Its assembly may be simple.*	Geometry
7	*It must be light, and easy to manipulate.*	Material to be used
8	*If needed, additional tools to be used may be commonly available.*	Local supplier
9	*During its fabrication, the removed material may be minimum.*	Max number of steps to do
10	*Assembly may be done quickly.*	Max number of components to be assembled
11	*Number of components may be minimal.*	Max number of executants
12	*The bearing extractor may be introduced within the available empty spaces of the front hub of the disc # 1 of the JT8D engine.*	Outer and inner diameters

In order to realize the FA of the bearing extractor tool, the relationships between the bearing extractor tool and all the elements that interact with it need to be identified; in order to do so, the method proposed by [6] is considered in Table 2 because of its rigor and the questions are straight and clear, allowing to be answered with easiness by beginners: columns 2, 3 and 4 describe the function between an element "A", and an element "B". In column 5 the question "*Is the function useful or harmful*?" is answered; in column 6 a similar question is made: "*Is the function necessary*?"; and in column 7 two more questions are asked: *Can B realize the function*? / *How*?

Continuing on the flux diagram of Fig. 5, the bearing extractor tool is not a complex system, so it is not necessary to decompose it into subsystems. Next, a functional dimensioning and tolerancing analysis is realized onto the bearing extractor tool, and the assembly of bearing No. 1. The first study allows to define the dimensions of the components according to their relative position; dimensioning and tolerancing shall be complete so there is full understanding of the characteristics of the product. According to [12], dimensions shall be selected and arranged to suit the function and mating relationship of a part and shall not be subject to more than one interpretation. An assignment of functional tolerances is needed and it need to be rigorous and well justified, mainly where it interacts with the bearing and the engine components. Thereafter, the geometric dimensioning and tolerancing (GDT) allows to geometrically describe the components and the assembly of a product. Both activities allow to corroborate the previous FA.

Table 2. Custom requirements as obtained by following QFD, [12].

No.	A	function	B	Is the function useful or harmful?	Is the function necessary?	Can B realize the function? How?
1	disc #1 front hub	gives support to	circular stepped cap	useful	yes	no
2	wrench	turns	full thread hexagon head screw	useful	yes	yes, by considering a bigger head of the screw, so it could be turned without a wrench
3	wrench	wears	full thread hexagon head screw	harmful	no	no
4	circular stepped cap	gives support to	tri-segmented cylinder	useful	yes	no
5	tri-segmented cylinder	grabs	bearing/oil slinger/air seal	useful	yes	no
6	bearing/ oil slinger/ air seal	damages/ misshapes	tri-segmented cylinder	harmful	no	yes, by considering a surface treatment, or by increasing the cross section of gripping edge
7	rectangular cross-section metallic ring	joins	tri-segmented cylinder	useful	yes	yes, by modifying the geometry of the segments
8	user	holds	extractor tool	useful	yes	no
9	user	applies a force/torque	wrench	useful	yes	no
10	disc #1 front hub	moves	bearing/oil slinger/air seal	useful	yes	no
11	circular platten	guides in rotation	full thread hexagon head screw	useful	yes	no
12	circular platten	locates	screws	useful	yes	no
13	screws	fix	tri-segmented cylinder	useful	yes	no
14	circular platten	holds in position	tri-segmented cylinder	useful	yes	no
15	circular stepped cap	holds in position	full thread hexagon head screw	useful	yes	no
16	full thread hexagon head screw	pushes	circular stepped cap	useful	yes	yes, with a pump or an hydraulic cylinder
17	circular stepped cap	generates friction	full thread hexagon head screw	harmful	no	yes, by lubricating the screw
18	circular platten	generates friction	full thread hexagon head screw	harmful	no	yes, by lubricating the screw
19	air seal	seals	bearing housing	useful	yes	no
20	bearing housing	fixes	bearing outer race	useful	yes	no
21	oil slinger	locates axially	bearing inner race	useful	yes	no
22	oil slinger	lubricates	bearing inner race	useful	yes	no
23	disc #1 front hub	locates radially	oil slinger	useful	yes	no
24	disc #1 front hub	locates radially	air seal	useful	yes	no
25	air seal	locates axially	oil slinger	useful	yes	no

As complementary, a Finite Element Method analysis (FEA) is realized [13] aiming to investigate the load conditions of the bearing extractor tool due to the tight fit condition of the bearing mounted on the compressor front hub of disc #1. A previous analytical analysis allows to calculate the required axial force to extract the bearing, considering the area of contact between elements, the pressure between them, their geometry and material, the friction force and the respective clearance tolerance. The pulling force is set at 21.35 kN (4,800 lb). Considering that the gripping edge that penetrates the bearing is submitted to flexure, and calculating it as a cantilever beam, a normal stress of 6,300 kPa and a shearing stress of 68.4 kPa, that stand for a principal stress (Von Mises, VM) of 120 MPa. A good correlation is obtained with the FEA for the principal stress (114 MPa). According to the results, it is at the clamp of the gripping edge that penetrates the bearing where the maximal principal stresses are reached (cf. Fig. 6), however they rest inferior to the yielding stress of the material.

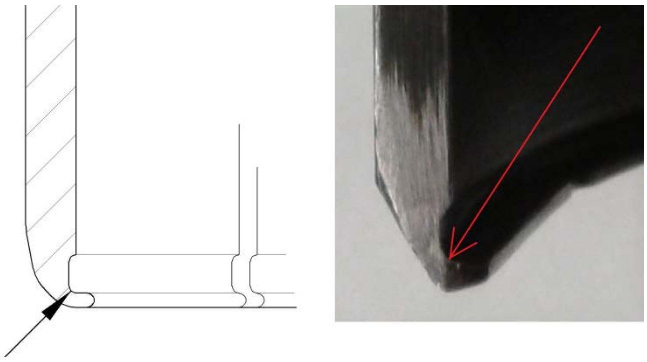

Fig. 6. Area of principal stresses.

The FEA also permits to justify the correct selection of the material of the tool to be fabricated. The material of the front compressor hub of disc #1 is established as an AISI 1045 medium carbon steel (stress at yielding σ_y = 310 MPa); as referred by [14]. The steel for the bearing is inferred as a M5 steel C 0.77-0.85, Mn ≤ 0.35, Si ≤ 0.25, Cr 3.75-4.25, Ni ≤ 0.15, Mo 4.00-4.50, S ≤ 0.015, P ≤ 0.015, V 0.9-1.1, W ≤ 0.25, Co < 0.25 from which the majority of engine bearings are made. Its structure is based on secondary-hardened martensite. The focus is on purity in order to avoid inclusions which initiate fatigue during rolling contact at high temperatures [18]. The material of the current bearing extractor tool is considered to be an AISI 4140 (chromium, molybdenum, manganese, low alloy) steel (σ_y = 415 MPa, E = 210 GPa) after hardness testing; material with high fatigue strength, abrasion, impact resistance, toughness, and torsional strength.

6. Innovation and improvements

The innovation of the extractor bearing tool is possible by considering the custom requirements expressed on Table 1 among the 39 inner characteristics or parameters defined by TRIZ, and by looking for how could they impact on each other. In this case the bearing extractor tool to be constructed "*may be resistant*" (custom requirement no. 4*; it should be as more resistant as possible*) and at the same time "*must be light*" (custom requirement no. 7; *it should be as more light as possible*). A common contradiction is found when one component may be either tough, or resistant, or robust; and light at the same time. The contradiction matrix, core of classic TRIZ, suggests four possibilities in order to solve this contradiction, as listed in Table 3.

Table 3. Principles considered to solve the " may be resistant" (↑)−"must be light" (↓) contradiction.

1. Segmentation
1.1 Divide an object into independent parts.
1.2 Make an object easy to disassemble.
1.3 Increase the degree of fragmentation or segmentation.
8. Anti-weight
8.1 To compensate for the weight of an object, merge it with other objects that provide lift.
8.2 To compensate for the weight of an object, make it interact with the environment.
15. Dynamics
15.1 Allow (or design) the characteristics of an object, external environment, or process to change to be optimal or to find an optimal operating condition.
15.2 Divide an object into parts capable of movement relative to each other.

By considering these principles, the quantification criteria of the custom requirements as listed in Table 1; the functions to be accomplished as described in Table 2; the FA; the tolerancing analysis, [13]; the GDT; and the FEA, [13], thus some modifications are proposed:

The redesigned bearing extractor tool consists of a metallic ring divided into two segments (instead of the three cylindrical segments of the current tool) that grab the bearing inner race. This ring is easily interchangeable, so another ring could be installed so as to remove the bearing outer race, a function that is not considered for the actual extractor tool (TRIZ' dynamics principle). Each of these rings are attached via removable links (chrome-plated rods) to a central body, the size of a slim cylindrical hand lamp (size to be determined by the principle to be considered for its functioning, either pneumatic, hydraulic -oil or water-, and the force necessary to extract the bearing). The piston rod gets in contact with the actual circular stepped cap (no. 15 on Fig. 3).

The gripping edge that penetrates the bearing inner or outer race is a sharp gripping border that penetrates the puller grooves of the bearing sufficiently to secure it to the disc for removal without excessive swedging and spreading effect of the shoulder against the bearing. This idea is taken from a similar bearing extractor tool, [16].

As the principal VM stress is 120 MPa at the root of the gripping edge for current operating conditions, the material to be considered for the construction of the bearing tool can be a 2024-T4 (σ_y = 320 MPa) or 7075-T6 (σ_y = 570 MPa) anodized aluminum, so the weight of the central body can be lowered. If additional strength is needed, a filament-wound barrel (use of polymeric composite materials) can be considered as a technological demonstrator of this kind of structure and in order to bear high pressures, cf. [17]. To be outlined in a future publication.

For easiness of manufacturing and assembly aspects (TRIZ' segmentation principle), the Design for Manufacturing and Assembly (DFMA) methodology is considered. By doing this most of the components are fabricated by turning with minimal removal of material. Connection between elements is realized with commercially available bolting hardware. The current design of the bearing extractor tool, as it can be observed in Fig. 3, is machined into three segments from a single, metal bar. After the bar is bored, it is milled into three segments, comprising a considerable amount of time and resources for each machining operation.

7. Conclusions

The way the FA was considered in this work as presented in the book written by Coronado et al [4], it facilitates the task, mostly for novices on classic approaches of FA.

TRIZ allows to introduce a different approach to the FA, resulting in innovative solutions.

By considering several methodologies such as QFD, RE, FEA, TRIZ, and DFMA a bearing extractor tool is redesigned. A tool designed and constructed by the manufacturer of the engine is analyzed such that the same functions are accomplished, moreover other functions are incorporated. QFD allows to consider the customer requirements. RE, as the central methodology, establishes a methodic and rigorous procedure that permits to describe the bearing extractor tool as a set of functions, rather than geometries; as part of this methodology, a functional dimensioning and GDT analysis define with certitude the product under study. With the FEA, corroborated with strength-of-materials models, it was possible to calculate the state of stresses and identify where it is critical. Finally, TRIZ assists on the development of a new concept in which the number of functions is increased, the material is lighter without risk of failure, the waste of material during machining is minimal, and composites are considered if more strength is needed. For this case, TRIZ is not used independently, it uses several other methodologies so as to accomplish its paramount objective of innovation. The developed bearing extractor tool is subject to register and patenting.

Acknowledgements

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Simple TRIZ Process "Quick TRIZ 2014" for non technical fields with resolving the dilemma in business, service, government policy and social conflicts systematically

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Abstract

Persons in non-technical fields for resolving the dilemma in business, service, government policy and social conflicts have complained that the conventional TRIZ looks like creative thinking tools for just technical, specially mechanical and manufacturing problems with unfamiliar words and many Engineering terminologies with technically solving principles.

Author and his colleague have tried many processes and researched to satisfy the requirement of the non-technical fields in Korea since 2010. Author has developed the simple TRIZ process, called by "Quick TRIZ 2014" for the non-technical fields with step-by-step contradiction or dilemma modeling procedures with modified box form of the conflict diagram of the TOC (Theory of constraints) on the D-A-G-E-V process at SAMSUNG like the D-M-A-I-C of six sigma process.

To resolve the contradictions it strongly recommends to apply the separation principles in time, in space and on conditions and use the other cheap resources first. The results has been proved as the effective process for both non-technical and technical problems for many cases since 2010 and updated every year.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: TRIZ Process; Non-technical field, Business Dilemma, Resolving conflict

1. Introduction

Conventional TRIZ has shown good results in technical fields, specially in mechanical domain. It has progressive potentials to apply the methodology and concepts of TRIZ to resolve dilemma in business, service, government policy and social conflicts.

But many terminologies of the conventional TRIZ are not familiar to general persons and the process has been complex for beginners to apply it to resolve conflict-type problems.

TRIZ users in Korea have complained that TRIZ looks powerful and systematic, but it was difficult to learn and apply it to solve their own problems.

Author with his colleague have developed the simplified TRIZ process, so called by "Quick TRIZ Process" since 2010 and updated every year.

In this paper, he explains the simple TRIZ process "Quick TRIZ 2014" for non technical fields with resolving the dilemma in business, service, government policy and social conflicts systematically

2. Logical and step-by-step problem modeling for conflicts in non-technical fields

Author has developed the simple TRIZ process, called by "Quick TRIZ 2014" for the non-technical fields with step-by-step contradiction or dilemma modeling procedures with modified box form of the conflict diagram of the TOC (Theory of constraints) on the D-A-G-E-V process at SAMSUNG like the D-M-A-I-C of six sigma process;

1. "**D**efine" stage
2. "**A**nalyze" stage
3. "**G**enerate" stage
4. "**E**valuate" stage
5. "**V**erify" Stage

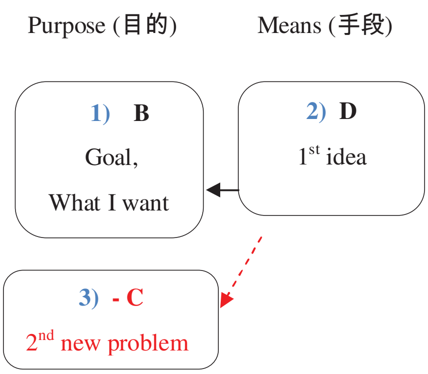
2.1 *“Define” stage*

The “Define” stage is composed of the name of problem, simple problem description written naturally in 2 or 3 lines and arrow sign from the current figure to goal (or ideal, solved) figure in one page of Power point file

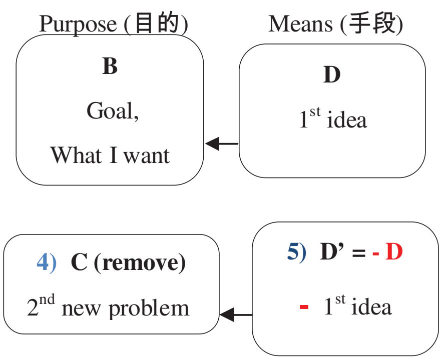
2.2 *“Analyze” stage*

The “Analyze” step is composed of the following steps;

a) Describe 5 causes of generating gap between current and goal, that is, problem. 5 causes stimulate the solvers more seriously on the causes of the problem.
b) Describe 1st (many times partial) solutions to eliminate the causes.
   If solvers do not the 1st solutions, search it by internet
c) If solvers satisfy the 1st solution, stop. That is to solve the problem early.
d) Otherwise select one candidate with the cause and one 1st partial solution by experience and the domain knowledge.
e) Insert the 1st partial solution into the “means (手段)” box D of the “Quick TRIZ Process” [1~5] and the content of the goal into “Purpose (目的)” box B.
f) And then, describe the 2nd new problem in applying the 1st partial solution to satisfy the purpose as follows;



g) Reverse the 2nd new problem, that is, describe to remove the 2nd new problem in the box C.
h) Reverse the status of the “means” as negative or contradictive means intentionally in the box D’.



i) Finally, describe the “common goal” box with goal B and removing the 2nd new problem C simultaneously.
j) And then, for general persons in non-technical fields call the “conflict between two contradictive purposes” instead of the “technical contradiction” and the “conflict between two contradictive means” instead of the “physical contradiction” in TRIZ.

2.3 *“Generate” stage*

The “Generate” stage is composed of idea generation steps by the three separation principles with separation in time, in space and on conditions and use other cheap resource first and then, applying the 40 inventive principles to satisfy the two contradictive purposes under “cheaper resource” concept.

2.4 *“Evaluate” stage*

On all ideas generated systematically with the 1st (partial) solutions and solutions using the separation and 40 principles, some criterions such as economics when applied, possibility to implement technically or on business, time to implement etc, may be evaluated by solvers and the domain experts.

2.5 *“Verify” stage*

On some good ideas evaluated, the CAE (Computer-aided engineering), prototyping and (simple) experiment may be applied for verification before real implementations.

3. Cases in non-technical fields

In Korea, in spring of 2014 year Korea government eagerly wanted to vitalize the Korean economics again in the name of “Creative economics movement” by releasing some regulation policies.

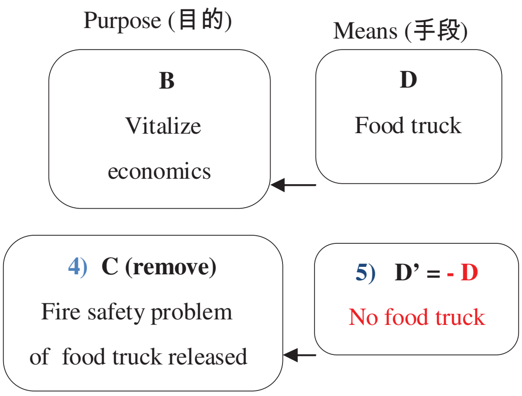
However, the releasing generates 2nd new problems many times.

So the minister of small and medium size company business association asked the author to give special keynote speech on case studies using TRIZ concepts and process on April 7, 2014.

The one case is on releasing the regulation on “food truck” that was prohibited at that time by Korean government for some small-scale business man.

1) Define stage; Figure with prohibition of food truck and the figure with worse business status of some small-scale business man (name of problem; food truck)

2) Analyze stage; as one means to vitalize the economics, releasing the “food truck” regulation.
   However, it may generate the 2nd new problems such as safely problem on cooking fire, sanitary problem on bad food, equality problem for the existing stores rented and some traffic jamming problem etc.
   So to solve the 2nd new problems forecasted needs not releasing the regulation on the food truck as current status now in Korea;



3) Generate stage; ideas generated by separation principles in time, space and conditions and using other cheap resource (remedy or means) with benching marking in other countries;

1. By separation in time → no idea
2. By separation in space → permission in only safe area
3. By separation on condition → permission if equipped with safety facility
4. By other cheap resource→ other economic promotions
5. "Prior action" of 40 principle → Fire extinguisher

and so on.

For other 2nd new problems on sanitary problem on bad food, equality problem against the existing and fixed store rented and some traffic jamming problem etc.

The related government employees and the domain experts may generate good ideas systematically with benchmarking some existing ideas in other counties such as permission around lunch time and special events such as at the Christmas season by applying the separation in time and big plaza and wide area such as the entertainment amusement park by applying the separation in space and on conditions and so on.

4) After evaluating some ideas, Korean government for SME may try the ideas by partially trial services at small regions for a few months for verification.

The "Quick TRIZ process 2014" has been applied to other case studies such as using other certificated on-line methods problem, movement of some departments of ministry to some rural areas outside of the capital city, Seoul for reducing the population and traffic problem in Seoul etc.

Many ideas by using TRIZ principles on the conflicts modelled in the Quick TRIZ step-by-step process systematically, have proved the effectiveness of this Quick TRIZ 2014 process in non-technical fields more and more after taking only 8 hours education and training.

4. Conclusions

The "Quick TRIZ Process 2014" has applied by general users and even students with more than 10 age to non-technical conflict type problems such as dilemma in management and social conflict and makes them to understand TRIZ process much easier with taking only 8 hours learning and training in Korea.

Because it uses the familiar words, "purpose (目的) and means (手段)" and their conflicts instead of technical and physical contradiction in TRIZ and the step-by -step process as the natural and logical thinking process of general persons.

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Online collaboration for TRIZ studies and problem solving - The experience of APEIRON, the Italian TRIZ association

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Abstract

The paper presents the experience of APEIRON, the Italian TRIZ association, about the organization of workshops open to both industries and academia where attendees can improve their own competences and skills on TRIZ-based systematic problem solving. Stemming from the main organizational problems encountered in the last five years, APEIRON tried to shift from live meetings to virtual meetings by the support of a WordPress website that allows different contributors to both work on the same case study and improve their own knowledge on TRIZ tools and methods. The first case study addressed through this novel online collaboration focuses on the development of an innovative waterbike within the limitations of the Open Waterbike Project.

Peer-review under responsibility of The International Scientific Committee ETRIA.

Keywords: TRIZCircle, knowledge transfer, knowledge sharing, workshop, online platform, openwaterbike

1. Introduction

APEIRON, the Italian TRIZ Association, has been founded in 2003 with the goal to promote development and diffusion of scientific and technical knowledge of systematic innovation and problem solving.

In order to reach this purpose, in 2009 APEIRON started organizing workshops where people employ TRIZ methodology and tools to solve an industrial case study.

The workshop formula is:

- one full day
- groups of 4 to 5 people with different background (academia, industry) and with heterogeneous level of TRIZ expertise: intermediate, beginner
- one tutor (TRIZ expert) to coordinate each group
- a real case study from industry proposed by one of the participant to the workshop
- share of the results by each group and discussion at the end of the day

At the Bergamo 2010 TRIZ Future Conference APEIRON presented the first 2 years results of the Workshop initiative. [1]

Up to now 5 workshops have been organized in 4 different locations (Milano, Bergamo, Trieste and Roma), some at the same time by teleconference to facilitate the participation for people from different regions. The workshops had a total of 92 people participating and an average of 18 people divided into 4 group; detailed data are shown on table 1

Table 1. Data for each of the 5 workshops

Year	Locations	Participants	Groups	Companies
2009	1	16	4	5
2010	3	28	6	6
2011	2	16	4	6
2012	3	18	4	4
2013	2	14	3	8

The graph in Fig 1 shows that people from academia (who are the majority in the first 2 workshops) disappear and the workshop became an initiative for industry. The number of companies have been pretty constant (average 6) with an increase in the last workshop; among these one company attended all the workshops and 3 companies attended 2 workshops.

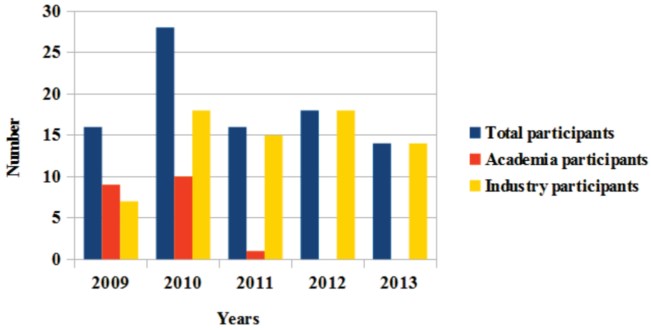

Fig 1. Participants per years

Unfortunately the one-day duration of the workshops limits both the work on the case study and the final discussion among the groups.

2. Workshop organizational problems

In further details, it emerged that the time of the workshop was almost fully dedicated to the development of the case study. However, the need to share the results with other subgroups carrying out the same activity truncated the work on the case study, sometimes leaving it suspended or not refined. This implies that the presentation of results can result just in a partially effective transfer of knowledge among the participants. Moreover, expert participants felt the need to approach the case study more rigorously. Besides, newcomers had just a short time to get in touch with new concepts, tools and methods.

In order to overcome the abovementioned limitations, the APEIRON members agreed to formulate this problem as a TRIZ contradiction, in order to better identify and define solution strategies capable of giving birth to a new kind of workshop presenting fewer problems.

Keeping the current duration of the workshop (short, as one workday) allows a wider audience to participate, but the quality of the activities related to the case study (e.g. analytical functional models, definition of contradictions as well as the application of the separation principles or the 76 standard solutions) does not undergo any improvement. Vice versa, a longer duration of the workshop (e.g. distributed on more days) allows the participants to dedicate more time to both the analysis of the problem and the synthesis of its solutions as well as to sharing the problem solving process with other participants. However, this option presents several organizational problems as, for instance, the need to gather several professionals from different companies around the same table, thus strongly impacting on their own, already busy, agendas.

In OTSM-TRIZ terms, e.g. refer to [2], the problematic situations can be interpreted as the contradiction of Fig. 2.

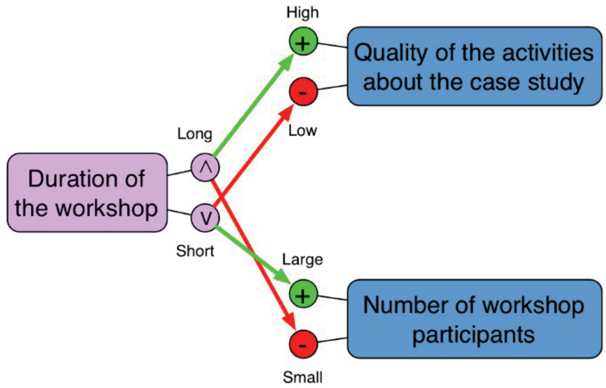

Fig 2. Workshop organizational problems seen as an OTSM-TRIZ contradiction

The ideal situation, therefore, should both allow the participation of people from different companies with poor or no impact on their “standard” activities and a satisfactory level of deepening for the problem solving activities, including a session for sharing the different TRIZ approaches followed by the participants (those using OTSM-TRIZ techniques, those using classical TRIZ,…).

The simple exaggeration of the contradiction (as for ARIZ85-C, Step 1.5 [3]) was sufficient to remove the related psychological inertia towards the identification of solution concepts and it suggested the APEIRON members to look for a solution having no time boundaries (e.g.: a permanent workshop) in a place where everyone can freely access, beyond the current limitations of space. The virtualization of the workshops was, then, considered as a very good opportunity to connect the different participants by harmonizing their own specific corporate or personal duties. To this purpose, the APEIRON executive committee informally called for volunteer members willing to start this kind of virtual workshop, thus implying the need of choosing an effective way for interacting and sharing content in a collaborative environment.

3. Co-working remotely: first steps

Some members of APEIRON agreed to be part of a group for the project and found a problem to be solved together with TRIZ.

The main objective is to devise a method and procedures to actively interact and the secondary objective is the resolution of that Case Study.

The initial information was collected during online meetings, using Skype. The contents were then synthesized and shared via e-mail.

The first requirement emerged was to share a folder where to collect both the information and the analysis of the problem. In this way it was possible to track the path and also individually process the information and then share them for comparison. For this reason, the APEIRON members chose to use the free service offered by Dropbox in order to share material with the presentation of the problem online.

The second requirement emerged from the group was to share knowledge and procedures of TRIZ and software to exploit them; in particular for charts and diagrams. Furthermore some guides relating to TRIZ-tools used, a glossary and a bibliography were included in the shared folder. In order to prepare diagrams, charts and models, free and multi-platform software (e.g. DIA and yED) were chosen as exploitable assets.

During online meetings Constraints, Requirements and Criteria for the evaluation of the solutions were defined and listed in a table stored in another file in the shared folder.

The APEIRON study group decided to use a shared OTSM-TRIZ Network of Problems [2] to keep track of the information, actions, and the reasons for the choices.

At this point, some considerations were made on the method: this approach made possible remote collaboration and a few moments of individual work to share and comment in group; however, Skype meetings remained fundamental to discuss the work and set tasks. The absent participants were not able to participate actively in the resolution of the problem. This problem can be partially solved by using other instruments for on-line conference and meetings recording (such as Zoom), but in any case, the comparison would have been very cumbersome, by e-mail and comments made directly on the processed and shared files. In addition, with this method it was not possible to share with people outside the group, not properly trained and selected, the path of problem solving during its course.

An effective solution to the contradictions of Fig. 2 should also facilitate comparisons and track the route taken and the information collected. The same solution would have to allow for a more intuitive and safe handling both material and participants in order to broaden participation and viewing the route done to people outside the group.

4. A WordPress blog for better collaboration

The problems and the relevant requirements exposed above, for the evolution of the on-line collaboration, brought the study group to a transition towards a different on-line platform for the collection of information and to track the route taken.

So APEIRON extended the workshop logic to an entire new website (www.trizcircle.com) where participants can pursue the same objectives of live workshops with more collaboration support.

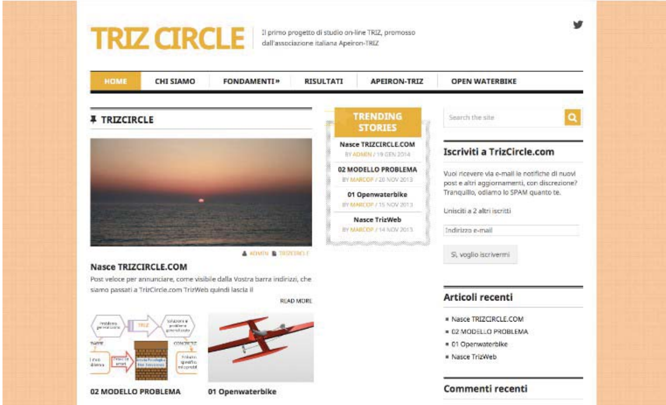

Fig 3. Screenshot of www.trizcircle.com

So the workshop logic maintained a series of scheduled one hour long on-line meetings on Skype to exchange viewpoints, insights, discussing the development of the study and to set the next tasks to do.

After an on-line meeting, every piece of information and the direction to go on are evaluated and a summary gets published into a webpage, so everyone involved can reach that information and react accordingly.

Among the available online tools and procedures to achieve this goal, a WordPress blog [4] represents one of the best opportunities, since it joins ease and versatility of use, by:

- providing a visible history easily at hand;
- collecting participants comments; and
- grouping together achievements and TRIZ foundations for support and for sharing with the rest of the world.

4.1. The visible history features

The visible history feature, expressed in greater details, is available when the structure of the blog is visualized in a time based layout, as a WordPress feature.

This layout can represent a diary of the development of the project, in order to maintain a track for everyone involved in the project. If one cannot participate at one on-line meeting, he or she will find the relevant discussion on an article (a blog post), to be up to date.

An interesting feature of WordPress allows the creation of pieces of content (posts or pages) that can be available to everyone on the internet or alternatively only to a strict group of people, with a special access. This feature offers the possibility to retain every piece of development for the participants of the study group and at the same time to decide what can be reached by everyone on the internet, to have a look to the development of this project of collaboration.

4.2. Collecting participants' comments

The commenting feature is a special feature, a kind of forum.

One can read an article and then write a comment that will remain, below that article, available for everyone to read and react, ideally with a smart reply to that same comment, to improve the discussion.

So the commenting feature gives the participants a possibility to improve an article, if something was not clear.

A participant can also ask questions to improve the understanding of that step or of that TRIZ tool, giving space to collaborative learning.

4.3. Grouping together achievements and TRIZ foundations

This aim can be achieve with the categories and tags features of WordPress.

With a good categories' classification, one can write at least two posts for each meeting.

If someone choose "achievements" in the upper menu of the website, it will visualize only posts under the achievements category.

5. TrizCircle first case-study: the Open Waterbike

The Open Waterbike Project (www.openwaterbike.com) is a collective web-enabled project aimed at designing and building an open-source high-performance long-distance pedal-powered boat [5].

TrizCircle first case-study, in support of the OWP, is the quest for the 'perfect Waterbike', a technical problem in need of inventive solutions. Indeed, while the OWP community was able to design and prototype good Waterbike, no breakthrough concepts has emerged as yet. A hand from the TRIZ community is therefore badly needed.

This standoff on the Open Waterbike Project makes the project a good testing field for TrizCircle. Indeed, its fascination is enhanced by the fact that the quest of the high-performance pedal boat has a very long history (more than a century long) of brilliant inventions and failed innovations. This long history of market failures could be now on the verge of a breakthrough since social and technical changes are pushing the interest towards more sustainable transportation systems and novel sports activities, while the availability of new developments in adjacent areas (e.g. electric bicycles) provides new technical modules of great interest.

There is therefore no shortage of significant cases for the pilot TrizCircle test.

The founder of the Open Waterbike Project (who is one of the authors) proposed three problems of interest at different levels, as follows:

1. The socio-technical problem including both the artefact (the Waterbike) and the social environment in which the new product is supposed to be introduced. This is a key problem for the project, since the Waterbike is not yet recognized as a sports fashionable implement, but on the contrary its market image is obfuscated by low-performance beach boats. Both technical performances and emotional design are necessary for launching the new product, and all the effort developed until now have been unsuccessful, calling for a more unconventional approach.
2. The 'fundamental' problem of developing a high-performance long-distance pedal boat compliant with the technical requirements that the OWP community have agreed upon, which should at the same time be a new stylish and not too expensive product. There is a contradiction between the two concepts, and all the compromise solutions developed by the community has not until now completely succeeded.
3. The transmission problem: the key component of the Waterbike is a mechanical transmission that needs to be highly efficient, dependable, and affordable. Here too there is ostensibly a contradiction whose solutions are not satisfactory as yet.

After an initial discussion the TrizCircle group decided to address primarily problem #2, because the Waterbike is a classic technical system, therefore the TRIZ methodologies for addressing it are more familiar and developed that those needed for addressing socio-technical problems like #1.

6. Conclusions

The on-line collaboration made available with the WordPress blog in www.trizcircle.com gave an important boost to this collaboration experience.

The structure of the blog and the administration of contents is good but it can be further improved.

The TrizCircle group of APEIRON is now working to build an automatic notification system to keep everyone in touch with each step. WordPress gives a simple e-mail notification system for new contents in the blog, but a more powerful notification system is still under investigation.

Other improvements for the site can be achieved giving more resources to people interested in TRIZ in general, such as a collection of TRIZ foundations oriented to an on-line collaboration or a better overview of the experience of the APEIRON's study groups.

As described the efforts have been focused to the on-line platform in order to disseminate the methodology and improvement of online collaborative learning. The case study has been used as an example for structuring the platform.

Now the platform is mature enough to allow people working on the case-study and apply their TRIZ knowledge to solve the OWP problem.

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TRIZ "knowledge spiral" (and first steps of ARIZ) solving Civil Engineering "thermal link" issue

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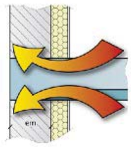
Abstract

For several years, a methodological approach called "knowledge spiral" has been successfully implemented in several different areas [1-7 & 9], including innovations in strategy in IT services, prospective study for industrial patents, student training in national education system, nuclear safety business, etc.

The present experiment is related to a more general study carried out by the authors on an Innovative Concrete Construction System, where the functional analysis according to OTSM-TRIZ led to a network of problems, including the "thermal link" issue. It appears in buildings insulated "from the inside" at the junction between floors and walls. The walls are correctly insulated, but the heat escapes by the floor, as the figure shows.



In the short run the actual building system will not be replaced by another system like "outside insulation", because house builders are not promoting this more technical and expensive solution. But, on the other hand, people who have their houses built are willing to improve the thermal quality of their home both for ecological and financial reasons, as the "inside insulation" is cheaper when pre-built.

What should be done to innovate in an easy and competitive way to stop or reduce the thermal link heat losses without changing the whole construction system and avoiding the market resistance to change?

After the problem reformulation, the authors applied the ARIZ algorithm and a mini-problem was then described, leading to some technical contradictions to solve. The most effective one was chosen and developed according to ARIZ. The algorithm was conducted up to sub-step 2.3 when a satisfying partial solution was found. This refined solution is now a specific and successful product on the market, which allows the reduction of thermal loss by 40% without changing anything in the way buildings are constructed today.

Keywords: TRIZ knowledge spiral; civil engineering; thermal link issue.

1. **Description of the problem**

<u>Main Function</u>: ensure the mechanical assembly and the load transmission from a horizontal element to a vertical element, avoiding the creation of a "thermal bridge" in the short run with the "by the inside" insulation system (cf. "thermal switch"), ideally adapted to the insulation "by the outside" later.

<u>Remark</u>: In case of an outside insulation there might exist « non thermal » inside connections.

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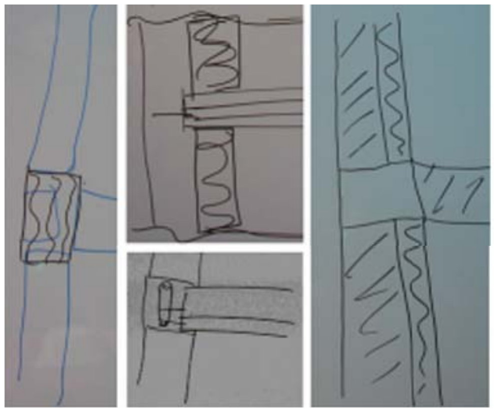
Vocabulary

1) Thermal bridge: discontinuity in the wall insulation, insulator break, flow, concentration and calorific loss, more important than on the insulated wall, i.e. “gaps”, weak points, possible heat losses.

2) Elements: vertical and horizontal concrete elements, plane and generally rectangular, but it can also be a complex joint form.

3) Insulation: the load bearing material itself is insulating (cellular concrete, monomur, bisotherm) or is covered by an insulating single or multi-layer material, which can also appear alone (example: a switch can replace part of a slab).

Sketch



Problem

The unknown zone must (1) transmit the loads coming from the higher wall and from the horizontal element to the lower wall, (2) play the role of the peripheral reinforcement, (3) remain homogeneous with the external plastering (no harmful effect), and (4) approach the insulating capacity of the walls.

2. **ARIZ analysis**

Step 1.1: Formulate the mini-problem

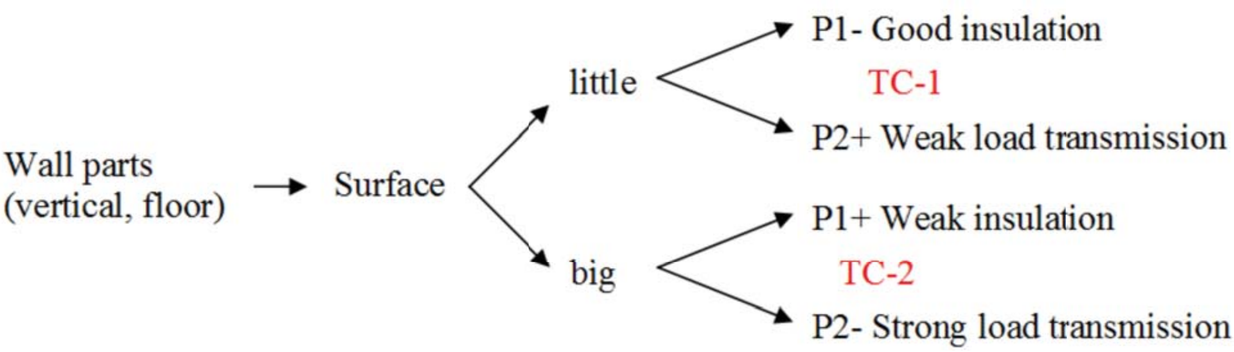
Components of the system

- Upper wall, lower wall, horizontal element (concrete, steel, insulating material)
- Unknown zone: reinforcement, concrete, steel, insulating material, wall parts, etc.
- Outside air, inside air (steam?)

Functions

	Functions	Components	Positive/Negative Effects (PE/NE)
F00			
F0	Connection homogeneity	All	PE: some homogenous cutting plans NE: some not
F1	Insulating Capacity	Insulating material, wall parts	PE: Insulation NE: brittleness
F2	Mechanical Assembly	Concrete, steel	NE: calorific loss
F3	Load transmission	Wall, floor	Neutral
F1x			

Mini-problem



Written contradiction

The system must bear the loads while minimizing calorific losses.

The system < to bear the loads while minimizing calorific losses > includes < wall parts and an insulating material >.

TC-1: If the contact surface between wall parts is small, then insulation is good, but the load transmission is imperfect.

TC-2: If the contact surface between wall parts is large, then insulation is imperfect, but the load transmission is good.

It is necessary, with a minimum change of the system < to allow load transmission between the wall parts, without weakening the insulation of the connection zone>.

Step 1.2: Define the conflicting elements

Brittleness: A – insulating zone
Product: B – wall parts

Step 1.3: Describe graphic models for technical contradiction

TC-1: A …> B
→
TC-2: A <… B
←

Step 1.4: Select a graphic model for further analysis

MMP (main manufacturing process) is the thermal connection, so let's keep TC-1.

Step 1.5: Intensify the conflict

Let's consider increasing the contact surface through the addition of a material to the wall parts, sufficiently insulating and solid not to degrade the insulation of the unit, and ensuring a good load transmission.

For example, is it possible to build a firmly linked group of thinner joists having the same transmission of loads with less contact surface (increasing the geometrical output of the section)?

Step 1.6: Describe the problem model

(1) Conflicting pair:
Tool: A –insulating zone
Product: B – wall parts

(2) Conflict Intensification:
Let us increase the geometrical output of the section (cf. « concretestyrene » as combination of concrete and polystyrene?)

(3) It is necessary to find an <unknown element> which keeps <a good thermal efficiency > AND <prevents from a lower load transmission >.

Step 1.7: Apply the Inventive Standards

Let's try the 40 Inventive Principles matrix.

A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Worsening Feature → / Improving Feature ↓	Weight of moving object	Weight of stationary object	Length of moving object	Length of stationary object	Area of moving object	Area of stationary object	Volume of moving object	Volume of stationary object	Speed	Force (Intensity)	Stress or pressure	Shape
		1	2	3	4	5	6	7	8	9	10	11	12
1	Weight of moving object	+	-	15, 8, 29,34	-	29, 17, 38, 34	-	29, 2, 40, 28	-	2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40
2	Weight of stationary object	-	+	-	10, 1, 29, 35	-	35, 30, 13, 2	-	5, 35, 14, 2	-	8, 10, 19, 35	13, 29, 10, 18	13, 10, 29, 14
3	Length of moving object	8, 15, 29, 34	-	+	-	15, 17, 4	-	7, 17, 4, 35	-	13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29
4	Length of stationary object		35, 28, 40, 29	-	+	-	17, 7, 10, 40	-	35, 8, 2,14	-	28, 10	1, 14, 35	13, 14, 15, 7
5	Area of moving object	2, 17, 29, 4	-	14, 15, 18, 4	-	+	-	7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4
6	Area of stationary object	-	30, 2, 14, 18	-	26, 7, 9, 39	-	+	-		-	1, 18, 35, 36	10, 15, 36, 37	
7	Volume of moving object	2, 26, 29, 40	-	1, 7, 4, 35	-	1, 7, 4, 17	-	+	-	29, 4, 38, 34	15, 35, 36, 37	6, 35, 36, 37	1, 15, 29, 4

Parameter to be improved: Area of stationary object (6)
Parameter not to be degraded: Stress or pressure (11)

➔ Recommendations among the 40 Inventive Principles: 10, 15, 36, 37

10: Prior action

➔ Integrate in the factory a pre-assembly system by button, spline, etc.?

15: Dynamicity

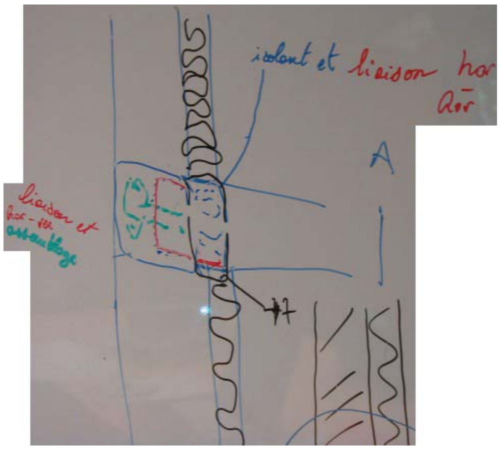
➔ Metal reinforcement (horizontally) clipped with the floor starter bar?

Remark:

Floor = Tank of calories
Wall and Floor = Calorific loss

➔ Dissociate the « mechanical node » from « thermal node »?

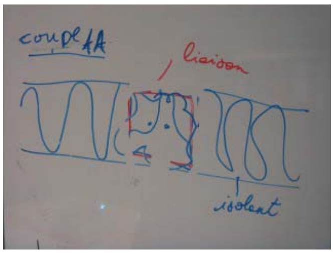
Step 2.1: define the Operational Zone (OZ)



Positive effect: volume in prolongation of wall insulation (minimal insulation rupture zone) **AND** volume in prolongation of plain walls (load optimal transmission zone)

➔ Positive effect Zone

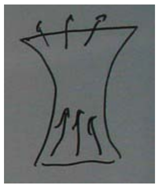
Negative effect: in section AA, the width of the joist support zone (passage of the load bearing elements through the insulation)



➔ Negative effect Zone

Remarks:

- Geometrically separate the zone related with the load transmission from the one related to insulation (cf. idea of the thermal switch)?



- "Trap or calorie funnel" which would make it possible to present a less useful apparent section for the calorific loss, before the load transmission zone, thus reducing the conflict of the zones or the intensity of this conflict?

Step 2.2: Define the Operational Time (OT)

Positive effect:
➔ Positive effect Time

Negative effect:
➔ Negative effect Time

Remarks on Operating Time:

1) In present work, there is no notion of time variability, for example of the calorific flow, its beginning, its end (no regulation requirements, we are working with an established continued rating.)

2) Laying dynamic?
   - Accidentally walking on the insulation during the laying etc.
   - Exceptional loading and "side effects" deforming the insulation?
   - Temporary phase verification may be different for thermal and structure (rules and regulation)

3) Durability in time (materials degradation, even if the concrete is perennial for tens of years)

Other Remarks:

1) Increase the length of the insulating device to reduce the calorific loss?

2) Calorific loss function of time? For example, by calculating consumption?

Step 2.3: define the Substance-Field Resources (SFR)

1) Internal resources:
   - Tool: insulating zone (restricted to the zone under the wall insulation only)
   - Product: wall parts (plain vertical walls, floor joists)

2) External available resources
   - Particular to each problem according to its characteristics: is air insulating if it's confined?
   - Common for every environment?

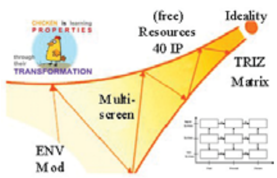
3) Super-system?

Remarks:
   - Air or « improved concrete with air bubbles or polystyrene balls » in addition to a « super insulation » thus allowing to reduce by half the cost of the insulating layer providing the same thermal efficiency?
   - Increase the section geometrical output?

3. Discussion

For several years, a methodological approach called "knowledge spiral" has been successfully implemented in several different areas [1-7 & 9], as a systemic inventive process based on Classical TRIZ, ARIZ and OTSM-TRIZ to quickly and easily overcome the obstacles and difficulties. It originates from a need for a pragmatic way to learn, teach and practice with busy professionals, and proposes a 4-step process to accelerate the usual 9 steps and 40 sub-steps of ARIZ for non-trained users.

Knowledge spiral 4-step process:
1) reduce the search area, break mental inertia
2) discover the main contradictions to solve
3) while (re)use available (free) resources
4) towards the ideal final result.



As a practical study case within a single day workshop for a R&D team just trained to TRIZ methods/tools and ARIZ process, the present experiment is related to a more general study carried out by the authors on an Innovative Concrete Construction System, where the functional analysis according to OTSM-TRIZ led to a network of problems, including the “thermal link” issue.

What should be done to innovate in an easy and competitive way to stop or reduce the thermal link heat losses without changing the whole construction system and avoiding the market resistance to change?

Instead of the “knowledge spiral” lighter process (understand the context of the problem, take advantage of the existing models, use the available resources, and then aggregate the concepts of solutions), the authors applied the ARIZ algorithm as usual, leading to a satisfying partial solution, then refined by the expert team, and now a specific and successful product on the market, which allows the reduction of thermal loss by 40% without changing anything in the way buildings are constructed today.

What did the team learn from this 1-day workshop with the ARIZ algorithm: based on previous training with successful examples using TRIZ methods and tools, and accustomed to the steps of ARIZ, the team's confidence in the workshop facilitator and their practice allowed them to follow all the steps of ARIZ and capitalize on the successive ideas gathered along the path.

At the beginning of the day, the team proposed this topic as a kind of "trap" for the facilitator and ARIZ, but at the end of the day, they were amazed to have quickly and easily produced themselves a full report to their CEO (with identified steps, explanation sketches and realistic proposals)...

4. Acknowledgements

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On the Effectiveness of Systematized Substance-Field Analysis for Idea Generation

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Abstract

This paper analyses the outcomes of a case study on application of the systematized Substance-Field Analysis (Su-Field) [1] to a real problem at Philips. A solution for a technical problem in a business area which had been thoroughly protected by intellectual property from many different competitors was required.
The goal of the project was to develop a wide range of ideas to cover as many feasible options as possible. Su-Field Analysis was used during the ideation stage after thorough situation appraisal, Function Analysis and patent search. A project team that consisted of 13 Philips employees from different backgrounds participated in a one-day Su-Field idea generation session that followed a set of extensive six weeks project activities. The Su-Field idea generation session resulted in 11 new concepts that, in turn, were transformed into seven patent applications.
The team members were surveyed on their Su-Field experiences. Survey results supported two hypotheses on the effectiveness of the procedure of systematized Su-Field as the means for a manual search of a user's knowledge repository. Su-Field had also been found effective in facilitating group creativity.

Keywords: TRIZ; Substance-Field Analysis; case study; idea generation; memory search.

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1. Introduction

Nomenclature	
TRIZ	Theory of Inventive Problem Solving
Su-Field	Systematised Substance-Field Analysis
STM	Short-term memory
LTM	Long-term memory

In the extremely competitive world of free-trade agreements, companies that do not innovate effectively are in distress, independent of their location and their production costs. A recent example of the impact of lack of creativity on company operations is Dell, which lost two thirds of their sales when Apple introduced iPads and iPhones and, as a result, was delisted from Nasdaq in October 2013 [2]. It is well known that application of creativity techniques can improve the outcome of idea generation [3]. Therefore, appropriately chosen ideation methodologies can play a substantial role in company's prosperity.

The Theory of Inventive Problem Solving (TRIZ) developed by Genrich Altshuller [4] is one of the three ideation methodologies that are used by professionals most widely (Brainstorming that was proposed by Alex Osborn [5] and the Lateral Thinking techniques that were put forward by Edward de Bono [6] are the other two).

While reflecting on cognitive foundations of TRIZ Belski and Belski suggested that, in essence, all ideation methodologies help users with the retrieval of knowledge located at the individual's long-term memory database (LTM) [7]. They have concluded that this retrieval process is hampered by the limitations of the short-term memory (STM). Based on their model of retrieval during problem solving, Belski and Belski proposed that an effective ideation methodology (i) "is expected to supply a practitioner with some additional cues which make the long-term memory search extremely efficient" and (ii) "must properly organise rehearsal to ensure that the relevant cues are kept in short-term memory for sufficient time to allow for a thorough search of the long-term memory database" [7].

By 2007 Belski systematized a classical TRIZ tool of Substance-Field Analysis (Su-Field is used to identify the systematized Substance-Field Analysis in this publication) [1]. He hypothesised that Su-Field can help a user "in systematically utilising the knowledge that you have gained over the years of study, and to efficiently exploit the knowledge which you will acquire in the future" [1]. Such high expectations on Su-Field effectiveness were grounded on the assumptions that

- The problem cues during Su-Field idea generation that are presented by five Model solutions are used sequentially one at a time, and, as result, do not overload the STM.
- Searching through the eight fields of MATCEMIB (Mechanical, Acoustic, Thermal, Chemical, Electric, Magnetic, Intermolecular and Biological) ensures that the cues are further 'narrowed down' to a single field (STM load is further reduced).
- Moreover, progressing through the fields of MATCHEMIB also engages a practitioner in an efficient rehearsal procedure, which keeps the cues in the STM for longer.

It has been reported that Su-Field was evaluated as an effective idea generation tool by both student and professionals [8-10]. Su-Field has also been effectively deployed for systematically establishing failure scenarios [11]. An engineer, who used the Su-Field procedure in his project work, for example, indicated that Su-Field "creates a framework for thoughts in relation to the physical placement of the various resources" and that "MATCEMIB is most helpful in directing thoughts and generating ideas that can really be outside of your supposed field of expertise" [10]. Although, there are many more informal positive evaluations of the Su-Field effectiveness in helping users to generate creative ideas, there is lack of formal appraisals of the Su-Field effectiveness.

This study is devoted to a formal evaluation of the effectiveness of Su-Field. It was conducted to prove the following hypotheses that have been supported by numerous informal assessments: (i) the eight fields of MATCHEMIB are very efficient for guiding users in searching their existing LTM knowledge repository for ideas; (ii) establishing conflict triads (Steps 1 and 2 of Su-Field) effectively focuses a user onto the problem to resolve; (iii) the Su-Field procedure suits both individual and group users.

2. The Su-Field Procedure

The following is a short description of the Su-Field procedure. During Steps 1 and 2 of the procedure, a user models the problematic situation in order to establish all the conflict triads (two substances and a field of their interaction) embedded in the situation. In Step 3, the user

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considers every conflict triad separately and applies five Model solutions represented in Figure 1 in order to resolve the problem.

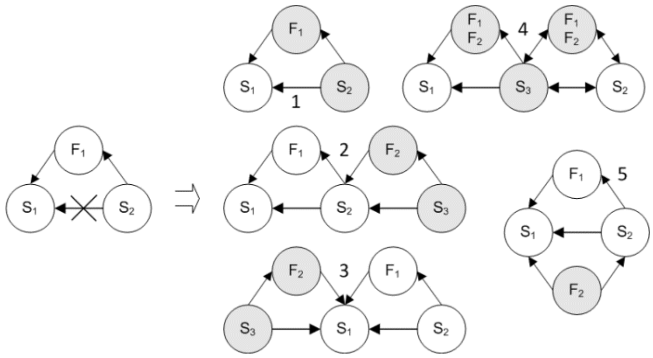

Fig. 1. Five model solutions of systematised Su-Field [1].

A conflict triad is depicted on the left hand side in Figure 1. The triad consists of two substances S_1 and S_2 and a field F_1 that are sketched as circles. A crossed arrow between these two substances identifies the conflict that requires resolution. Five Model solutions are shown on the right hand side in Figure 1. Each model solution is identified by its number. These Model solutions propose the user to add more substances and fields in order to resolve the conflict. All these additional substances and fields are depicted in Figure 1 as grey circles.

Solution ideas for every Model solutions are recorded when the user sequentially considers which of the interactions that are suggested by the eight fields of MATCEMIB are suitable for implementation of the appropriate Model solution [1]. Once all the possible solution ideas have been generated, the most suitable solution idea is then chosen for implementation.

3. Methodology

3.1. Project X team activities

Su-Field was used by a team of 13 Philips employees from different backgrounds. The participants were expected to get a solution for a technical problem in a business area (Project X), which had been thoroughly protected by intellectual property by other companies. The goal of the team was to develop a wide range of ideas to cover as many feasible options for Project X as possible. The team's activities on Project X can be divided into four stages: (i) the Analysis stage, (ii) the Function Analysis and the Industry Scouting stage, (iii) the Ideation Stage and (iv) the Feasibility stage.

The Situation Analysis stage was performed during a four week period. It was devoted to analysis and mapping of the existing patents and establishing the existing possibilities. This gave an overview of the patent-protected areas and also served as a starting point for later screening of ideas.

Function Analysis [12] resulted in improved understanding of the project's context and provided insights into the super-system in which the solution had to fit. During the Industry Scouting exercise the team investigated existing working principles that could be used for Project X. The Function Analysis and the Industry Scouting stage occupied the team for two weeks. The information from this stage was used for the input to the ideation phase.

The group used the Su-Field procedure during the Ideation stage that was completed in one day.

After the Ideation stage, during the Feasibility stage, the resulting ideas were clustered and screened on feasibility and innovativeness, then categorised on their working principle. This served as an input for the concept creation. The Feasibility stage lasted for about four weeks and involved members of the initial Project X team as well as new participants. These additional team members were invited to provide advice in knowledge domains that the original team members lacked expertise.

In a number of sessions that followed, experts discussed the ideas, enriched them with functional diagrams, sketches, technical calculations and the results of simple experiments.

3.2. Post session survey

All the group participants were invited to participate in a survey. This survey was conducted 13 months after the Ideation stage. It consisted of 20 questions and was paper-based. Five questions were devoted to general information on the group member. Two questions asked the participants to reflect on their experience with Su-Field. The rest 13 questions enquired of the various aspects of application of the Su-Field procedure. These latter questions used the Likert scale of 5 (from 1 – strongly disagree to 5 – strongly agree).

4. Results

4.1. The outcomes of the Ideation stage

The Ideation stage resulted in 11 new concepts. Three of these concepts were chosen for further testing and investigation as there was some doubt as to whether they actually could work. All tests showed that the ideas were feasible. After this seven patent applications were lodged.

4.2. Survey results

Nine team members returned in their survey forms. All survey respondents were male with the educational level from the Bachelor to PhD. Most of the survey participants were experts in their fields (worked in their professions for over 10 years). Eight of them worked in research and development. Only three respondents possessed some knowledge of TRIZ. Practically all team members were familiar with ideation tools of the Brainstorming family (Brainwriting and Braindrawing) and/or Lateral Thinking tools (random word/image).

The team members were positive about their experiences with Su-Field. Most of them assessed the procedure as simple to follow and easy to remember. The following are just some of their opinions: “It [took] some more time but it forced me to think about technical aspects I maybe would have done without it”. “I think the eight categories work really well to help you think about other solution direction.” “Helps to use different solutions principles.” “The examples for each category really helped to think about the relation between a general subject and possible solutions.” “It provides a systematic approach to make sure you get inspiration from all possible angles to solve your problems.”

Table 1 contains responses to six survey questions that further clarify the opinions of the team member on the impact of Su-Field.

Table 1. Mean values (M) and standard deviations (SD) for responses to some survey questions (5 – strongly agree, 1 – strongly disagree).

	Question	M	SD
1	In my view the use of the Su-Field procedure generated ideas that would have been overlooked otherwise	4.11	0.57
2	Building a simplified model in form of a Su-Field helped me to focus my attention on the most vital issue of the Project X	4.00	0.94
3	The Eight Fields of MATCEMIB were extremely helpful in generating ideas for Project X	4.00	0.82
4	The Eight Fields of MATCEMIB have helped me to thoroughly search my knowledge for solution ideas on the Project X	4.11	0.74
5	Su-Field is extremely effective for group idea generation	4.22	0.63
6	Su-Field is extremely effective for individual idea generation	3.44	1.07

5. Discussion and Conclusion

The opinions of the team members on the success of Su-Field in facilitating idea generation were positive. All survey respondents agreed that Su-Field helped the group to generate ideas that would have been overlooked otherwise (see the response to question 1 in Table 1). This team’s opinion is further supported by the fact that as a result of the one-day Su-Field Ideation stage (that followed six weeks of the team’s Project X activities) the team was able to propose 11 new concepts. Moreover, these opinions of the team members fully agree with the informal evaluations by the Su-Field users that have been reported so far.

The feedback from the survey participants on question 2 in Table 1 supports the second hypothesis (establishing conflict triads (Steps 1 and 2 of Su-Field) effectively focuses a user onto the problem to resolve). This finding can also be considered as additional support for the model of retrieval during problem solving proposed by Belski and Belski [7, 13].

The responses to questions 3 and 4 in Table 1 fully support the first hypothesis (the eight fields of MATCHEMIB are very efficient for guiding users in searching their existing LTM knowledge repository for ideas). This hypothesis is also supported by the numerous comments from the team members that are presented in the results section.

Survey responses to questions 5 and 6 in Table 1 suggest that the Project X team members assessed the Su-Field procedure as well suited for the group idea generation sessions. Effectiveness of Su-field in group sessions is further supported by the following opinion of a team member: “I think it [Su-Field procedure] is most suitable for a group ideation session because it is most fruitful when specialized knowledge (an expert) is available for each category.” Essentially, the third hypothesis (the Su-Field procedure suits both individual and group users) is only partly supported by the survey responses.

There are a number of weaknesses of this study that needs to be mentioned. First of all, the team members were invited to participate in the survey many months after the Su-Field Ideation stage on Project X took place. Therefore, it is possible that the survey responses of the team members are somewhat different from the responses to the same questions they would have given directly after the Su-Field day. On the other hand, collecting team opinions on the effectiveness of the Su-Field Ideation stage after their views have settled and the 11 new concepts have been thoroughly investigated (plus seven patents were lodged) makes the opinions of the team member on the Su-Field merit more justifiable.

Secondly, although only nine survey forms were returned from 13 Project X participants (69%), survey results cannot be considered as highly accurate statistically. In order to achieve sound statistical accuracy more studies on the effectiveness of Su-Field in real company projects are needed.

Overall, this study was able to formally demonstrate that the systematized Su-Field procedure can effectively facilitate idea generation and even offer novel solution ideas to the users after they have deployed other ideation methodologies.

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